Spatial and Temporal Variations in Population Dynamics of Few Key Rocky Intertidal Macrofauna at Anthropogenically Influenced Intertidal shoreline

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C E R T I F I C A T E

I have pleasure forwarding this thesis of **Mr. Ashokkumar G. Vaghela** entitled, "**Spatial and Temporal Variations in Population Dynamics of Few Key Rocky Intertidal Macrofauna at Anthropogenically Influenced Intertidal shoreline**", for acceptance of the Degree of Ph.D. in Zoology.

This thesis contains interpretation of original experimental findings observed by the candidate in the field of Marine Biology and Coastal Ecology.

It is further certified that **Mr. Ashokkumar G. Vaghela** has put in more than six terms of research work in my laboratory.

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Chapter - I: Introduction

Marine and Coastal Ecology

The Ocean is great reservoir of life, but most studies on biological diversity relate to terrestrial systems and thus, the knowledge of marine biodiversity lags far behind than that of the land. The study of organisms which deals with marine habitat is known as "Marine ecology". The marine fauna is rich and varied. The coastline encompasses almost all types of intertidal habitat. Each local habitat reflects prevailing environmental factors and is further characterized by its biota. The coastal zone comprising, land mass, intertidal areas and inshore waters, is characterized by ecosystem diversity. The interaction between land and sea involves physical and chemical processes, which produce characteristic shapes of coastline. Thus in a coastal zone the terrestrial ecosystem has its influence on the sea and vice versa. The physical features of the land bordering the sea, wind speed, water currents, salinity, pollutants, light, temperature and number of the related factors influence coastal productivity and its species diversity.

Intertidal ecosystems are valuable sites for investigation of relationships between biodiversity and ecosystem function. Various attributes of the marine environment have been incorporated into experimental systems to test empirical relationships using an approach that is analogous to those used in other systems. The bounty of goods and services provided by coastal and marine ecosystems attracts population increase in coastal areas. These goods and services include food that to most coastal societies is the only source of protein. Coastal areas support the economies of many maritime nations through fisheries, shipping, petroleum exploitation, seabed mining, energy and tourism. In addition to these tangible benefits to humanity, coastal and marine ecosystems perform critical ecological functions. The coastal strip is where the human population lives. A significant proportion of the World's human population resides in the coastal strip not exceeding 150km from the shoreline. For example, it is estimated that 60% of the world population lives in the coast and about 70% of the World's cities with populations exceeding 2.2 million are near tidal estuaries. It is also estimated that the population of the coastal zones will double by the year 2020 (Olsen et al., 1999). However, the resources that we depend on are declining at an unprecedented rate and the environment that we enjoy is degrading faster than we can ever imagine. There has been a long-standing understanding that users have an open access to marine resources. Marine biodiversity is of direct benefit to society as a food source, potential pharmacopoeia (Hunt and Vincent, 2006), stabilizer of inshore environments (Jie et al., 2001) and regulator of atmospheric processes (Murphy and Duffus, 1996). Marine biodiversity provides indirect benefits to society through ecological stability (Menge et al., 1999) and benthic-pelagic coupling (Ponder et al., 2002) which contribute to self-sustaining marine ecosystems. Marine biodiversity also has recreational, aesthetic and intrinsic value (Wilson 1994; Ponder et al., 2002).

Rocky Intertidal Shore

Rocky shores are one of the most easily accessible marine habitats and are a transition zone between the land and sea. Many animals and plants in the rocky intertidal such as barnacles, limpets and seaweeds, are sessile as adults and can be quickly and easily surveyed using non-destructive methods. The rocky intertidal has a long history as a test area for important concepts in ecology and a good knowledge of processes and species biology. Rocky shore organisms are strongly influenced two processes - tidal regime and exposure or wave action. As intertidal habitats are transitional between the terrestrial and marine realms, sessile animals and plants growing on the shore are periodically immersed in seawater and then exposed to air as the tides rise and fall. When the tide goes out, the phenomenon of zonation is manifested - horizontal bands or zones of organisms. This is true for both plants and animals. Each zone has a particular colour or texture from the organisms inhabiting that particular zone.

Wave action put forth strong mechanical stresses on intertidal organisms and is an important force shaping the form of rocky shore communities. Wave action varies greatly along the shore depending on factors such as topography of the coastline. Wave action can extend the vertical distribution of organisms on the shore. Many rocky shore animals are sessile with the most conspicuous being barnacles, mussels, oysters, chitons, sea anemones and tubeworms. Mobile macrofauna such as starfish, sea urchins, crabs and marine snails range over the intertidal when either exposed or submerged while fish will move in with the tide to feed on the animals and plants in the intertidal zone. Rocky intertidal communities have been intensely studied for a long time due to their accessibility and richness of natural resources. However, in spite of the long history of ecological studies conducted in this ecosystem, many questions related to the spatio-temporal structuring of the communities remain unexplored.

Rocky shores are generally visited by large numbers of people, particularly shores near major cities, for aesthetic reasons, to collect food or bait or for fishing. Harvesting for food and bait can disrupt rocky shore communities, and also deplete some species while allowing for increase in dominance of other species. Coastal development will change hydrology and topography of areas and thus the characteristics of rocky shore communities. Alteration of water quality and input of pollutants will impact on rocky intertidal communities. The rocky intertidal habitat has a very rich diversity of organisms. The organisms are well adapted for withstanding tremendous surf-exposure. Also tolerance to desiccation (low tides during the summer days), temperature changes, and salinity changes (rainfall during low tide).

The Intertidal region is the section of land separating the earth and the sea, which is located between the tidal rise and fall of the coastline. Ecological diversity within this region can be very high, with species from many classes and genera often present. Vital ecological communities can also be found in the intertidal regions, emphasizing the importance of this area of the shore as a habitat. The area is strongly influenced by the tides, which allow sea levels to fluctuate between high and low. Tidal variations affect the number of species immersed by the sea, therefore dictating the regions ecology. Other climatic factors such as temperature, humidity and wind direction, also affect community structure in the Intertidal zone. The extent of stress experienced by the region is dependent on the intensity of various environmental factors, of which vary with latitude.

The intertidal zone is the area between low and high water marks. This is a zone of interaction between the sea, land and air, which is one of the most interesting regions of the marine environment. Organisms that live in the intertidal zone frequently needs to deal with changing environmental extreme and are known to be hardy and diverse. Intertidal animals experience extreme physiological stress during the low tide period and those species inhabiting the upper intertidal zone are often more tolerant of thermal and desiccation stress than those found in other zones (McMahon, 1990; Sokolova et al., 2000). The intertidal zone is an astonishing glimpse at the food chains, interactive life cycles, and many special adaptations to this difficult environment. This zone is considered as the most productive with greatest diversity of life of any ecological area of the world.

The Intertidal zones natural productivity provides food, not only for humans, but for marine species and migrating birds. Furthermore, Intertidal regions form parts of many landscapes that appeal to visitors, allowing the formation of important recreational and tourist economics. The zoned distributions of marine organisms within the Intertidal region are created by their varying responses to environmental stress. These stresses, including desiccation, temperature and light penetration, are directly related to the tidal environment. Tides are produced by the gravitational pull on the earth by the sun and the moon. The shores water level constantly changes, and the height to which the tide rises and falls varies daily. The tides control the shore environment by affecting the periods of submersion and emersion. At high tide marine organisms are not subjected to desiccation stresses, whilst temperature is also constant. Oxygen, carbon dioxide and nutrients will also be readily available. During low tide, emersion factors including heat, light and desiccation are strong, causing intertidal organisms to become less efficient at feeding and respiring. Consequently, the only animals to be found in areas regularly emerged by the tide, are those that have adapted to these extreme conditions.

Zonation in the intertidal environment

Throughout the intertidal area, a very fascinating phenomenon known as zonation occurs. Zonation is the vertical banding of the organisms. These distinct bands occur in part from many complex physical and biological factors that affect marine organisms. The zonation of organism along altitudinal, latitudinal or intertidal gradients is a reflection of their response to both physical and biological factor (Parulekar, 1981; Mettam, 1994). Harsh environmental factors such as waves and temperature stress from exposure all contribute to formation of this phenomenon. The intertidal zone, also known as the littoral zone, in marine aquatic environments is the area of the foreshore and seabed that is exposed to the air at low tide and submerged at high tide, i.e. the area between tide marks. A typical rocky shore can be clearly separated into four zones known as the supratidal zone (spray zone), high tide zone (upper littoral zone), mid tide zone (middle littoral zone), and low tide zone (upper littoral zone).

Spray zone, which is above the spring high-tide line and is covered by water only during storms. This relatively dry area is sparsely populated. Few organisms can withstand the extreme fluctuations in moisture, temperature and salinity found in this zone. It is the most marginal and nutrient-poor part of the tidal-zone ecosystem. The high tide zone is flooded during high tide only, and is a highly saline environment. Parts of this region are exposed to the air for long period as the tide recede. The abundance of water is not high enough to sustain large amounts of vegetation, although some do survive in the high tide zone. The predominant organisms in this sub region are barnacles, chitons, crabs, green algae, limpets, snails and some marine vegetation. The high tide zone can also contain rock pools. Life is much more abundant here than in the spray zone.

The middle tide zone is submerged and flooded for approximately equal periods of time per tide cycle. The water comes here twice daily but also retreats twice daily. Consequently temperatures are less extreme due to shorter direct exposure to the sun, and therefore salinity is only marginally higher than ocean levels. However wave action is generally more extreme than the high tide and spray zones. His environment contains a more diverse group of organisms, than either the splash zone or high intertidal zone. The middle tide zone also has much higher population of marine vegetation, specifically seaweeds. Organisms in this area include anemones, barnacles, crabs, green algae, mussels, snails and sponges. Apart from being more populated, life in the middle tide zone is more diversified than the high tide and splash zones.

The low intertidal zone is mostly submerged; it is only exposed at the point of low tide and for a longer period of time during extremely low tides. This area is teeming with life; the most notable difference with this sub region to the other three is that there is much more marine vegetation, especially seaweeds. There is more species richness in the lower intertidal because the organisms are submerged in water most of the time, so more interaction takes place. Organisms in this zone generally are not well adapted to periods of dryness and temperature extremes. Some of the organisms in this area are brown seaweed, crabs, green algae, Nudibranchs, sea cucumber, sea stars, sea urchins, shrimp, snails and sponges. Typically, *Zooanthus* coelenterate dominates this area. Creatures in this area can grow to larger sizes because there is more energy in the localized ecosystem and because marine vegetation can grow too much greater sizes than in the other three intertidal sub regions due to the better water coverage: the water is shallow enough to allow plenty of light to reach the vegetation to allow substantial photosynthetic activity, and the salinity is at almost normal levels.

The Benthic Community

Organisms that habitually live in or near the seabed at any time during their life history constitute the benthos. The benthic community is composed of a wide range of flora, fauna from all levels of the food web. The three benthic life strategies are (1) sessile: attachment to firm surfaces (2) mobile: free movement of the bottom or (3) burrower: burrowing in sediments. These life styles correspond to the principle ways of obtaining food among benthic organisms: filtering from seawater, predation and digesting sediments. Benthic organisms must complete for living space as well as food.

Benthic communities in general, are sessile and slow moving in nature. Among the benthic animals almost 75% live on the firm substrates (rocks, corals, etc.), 20% on sandy/muddy bottoms and only 5% are planktonic (Thorson, 1957). Those organisms having body size >500 µm (Holm and Mclntyre, 1971) are called macrofauna (all macro-invertebrates, macrophytes and selected vertebrates like fish). It mainly constitute 3 modes of feeding such as filter feeders (bivalves, sponges, ascidians, worms, barnacles), browsers (amphipods, isopods, gastropods etc.). They prefer hard bottom and silty sand rather than muddy bottom.

The two major invertebrate groups that currently contribute most to human diet are crustaceans and molluscs. Most of the exploited species are Marine. Some have been developed into major commercial industries, while others are captured non-commercially. Exploited species include molluscs such as mussels, squid and octopus; crustaceans such as prawns, lobsters, and crabs; as well as holothurians echinoderms (sea cucumbers) and echinoid (sea urchin or sea egg). Molluscs and crustaceans are widely collected by recreational fishers, while other invertebrate species, such as beach worms and bloodworms (polychaetes) are commonly exploited for use as bait.

Significance of Benthos

Measure of ecological diversity and species abundance require adequate species recognition. Benthos is the key component of the marine ecosystem. Their ability to adapt in various habitats makes them important as food for larger organism, especially the demersal fishes. The sediment organic matter from the water column is effectively consumed and converted into invertebrate benthic biomass dissolved organic matter and inorganic nutrients by benthic organism. Therefore, they are also called as conveyor belt organisms (such as polychaetes and nematodes). The nutrients released from the sediment due to bacterial degradation of organic matter diffuse and disperse fairly rapidly into the overlying water and influence the primary production, which in turn triggers zooplankton production in the marine environment. The benthic ecosystem of coral reefs, mangroves, intertidal beach and mudflats serves as a good feeding, breeding, spawning and nursery ground for many marine organism of economic importance, variety of migratory and resident birds, fishes, sea mammals and reptiles.

Mollusca

The phylum mollusca is a large assemblage of animals having diverse shapes, sizes, habits and occupy different habitats (Subba Rao, 1993). Based on their habitat preference, molluscs can be classified into aquatic and land communities. Although molluscs are common components of the benthic communities, their role in the dynamics of the aquatic ecosystem and their contribution to biomass production is not well known. Marine molluscs have received more attention because of their aesthetic and gastronomic appeals (Subba Rao, 1993). Molluscs of the rocky shore demonstrate ecological succession from high to low water mark, each species being most abundant in a certain horizontal substratum. Amongst these mollusks, the gastropods are typically inhabitant of rocky shores at the intertidal level and as such they are subjected to extreme environmental conditions. This situation allowed one to correlate, in the field, the distribution, the frequency, variations in abundance and biomass, growth, mortality, reproductive periods and existence of phenotypes in different populations of gastropods with relation to contrasting and changing environmental conditions (Bacci and Sella, 1970). Molluscan community structure are effective indicators of overall ecosystem health and species diversity (Rittschof and McClellan-Green, 2005), making them ideal study organisms of conservation and biodiversity study.

The diversity of molluscs encompasses food, dyes, pests, pathogens, parasites, and pearls. Their variety is reflected in the range of body forms and ways of life. Molluscs include the coat-of-mail shells or chitin, marine and freshwater snails, shell-less sea slugs, tusk shells, clams, mussels, octopuses, squids, cuttlefishes, and nautiluses. While some molluscs can swim, most are attached or live creeping along the bottom. The molluscs contain animals that are mostly crawlers or completely sedentary. Their slowness results from having no legs and using a single foot. The only group of molluscs that became active swimmers was the class of Cephalopods which include octopus, squids and the chambered nautilus. Their evolution illustrates ways which modifications of the body plan can open up new ecological options and close others as well as give rise to new kinds of animals.

Molluscs dominate known biodiversity in the marine environment. Gosliner et al. (1996) estimated that molluscs comprises up to 60% of total biodiversity. Molluscs are essentially the insects of the sea. Squids, cuttlefish, octopus, bivalves, gastropods, chitons and the worm-like aplacophoran are all molluscs. They occur in all marine habitats, from upper intertidal to the depths of the oceans, in the water column itself, and geographically in polar, temperate and tropical regions. Molluscs are found in a wide variety of habitat types and niches within each habitat; sub as in or under sand and rocks, burrowed into rocks or wood, as parasites on other species etc. Their ecology is also diverse. For example, various species are herbivores, carnivores, scavengers, filter feeder, some have single celled algae in their tissues that the primary producers and other are parasitic. Mollusca colonized land, fresh and salt water, and most all marine habitats, rocky, coral, sandy, muddy, boulder, shingle, transition zones, mangrove swamps, estuaries.

The phylum mollusca is normally divided into 8 classes of very unequal importance; the most important class of living molluscs is the gastropod comprising more than 80% of all living molluscs species. Molluscs shells introduce complexity and heterogeneity into benthic environments and are key elements of habitat structure, affecting a variety of processes from population structure to ecosystem quality. This taxonomic and biological diversity makes molluscs an attractive indicator group for biodiversity studied. Since prehistoric times, humans have exploited molluscan resources such as shellfish have been traditionally used for various purposes.

Population Ecology

Studies on population dynamics, biomass and growth are very essential in understanding the effects of various factors governing these aspects in different gastropod snails inhabiting the intertidal zone. A population is a collection of individuals of the same species that live together in a region. Population ecology is the study of populations (especially population abundance) and how they change over time. Crucial to this study are the various interactions between a population and its resources. A population can decline because it lacks resources or it can decline because it is prey to another species that is increasing in numbers. Populations are limited by their resources in their capacity to grow; the maximum population abundance (for a given species) an environment can sustain is called the carrying capacity. As a population approaches its carrying capacity, overcrowding means that there are fewer resources for the individuals in the population and this result in a reduction in the birth rate. A population with these features is said to be density dependent. Of course most populations are density dependent to some extent, but some grow (almost) exponentially and these are, in effect, density independent. Ecological models that focus on a single species and the relevant carrying capacity are single species models. Alternatively, multi-species or community models focus on the interactions of specific species.

Anthropogenic Disturbances

The coastal environment is being altered at ever-increasing rates, often without looking ahead at future consequences. Most of the threats to biodiversity in coastal zone are the demographic trends of increased human population densities and rapid industrialization in coastal areas (Gray, 1997). Human activities, both directly and indirectly are responsible for current high rates of biodiversity loss; habitat loss; degradation due to agricultural activities. The intertidal regions form part of many landscapes that appeal to visitors, allowing the formation of important recreational and tourist economics (Bowers, 1999). These attract humans towards the intertidal area and provoke disturbance of its habitats, intensive exploitation and usage of its resources, thus creating an extraordinary pressure on the existing communities. Due to the fact that many rocky intertidal communities, globally and locally, are subjected to a variety of stresses caused by human activities such as exploitation, trampling, seaside strolling, fishing (Moreno et al., 1986; Kingsford et al., 1991; Povey and Keough, 1991; Keough et al., 1993; Addessi, 1994; Lasiak and Field, 1995). Though biological communities of rocky shores may have the capacity to withstand or rebound from impacts generated by natural disturbances, large increase in the level of human disturbances inevitably alter the pattern of natural variability at various scales of organization within the community. This is because anthropogenic stresses are superimposed on stresses caused by natural environmental factors (Raffaelli and Hawkins, 1996). Strong linkages often exist among species (Paine 1980) and therefore, rocky shore communities are sensitive to human induced disturbances that may play an important role in the shaping of species diversity through indirect influences on species abundances (Keough and Quinn, 1998; Brown and Taylor, 1999; Milazzo et al., 2004). Through the years, humans have substantially affected intertidal zones across the globe and this scenario has been proven by human exclusion experiments in rocky shore communities (Castilla and Bustamante, 1989; Hockey, 1994), although this approach is difficult to implement in most places.

The coastal environment is being altered at ever-increasing rates, often without looking ahead at future consequences. This is due to a multitude of human activities. The coastal zone receives a vast quantity of sewage waste, dredge spoils, industrial effluents and river runoff. These markedly affect the composition and quality of coastal environment, causing marine pollution. Coastal area is the most dynamic and productive ecosystems and are also foci of human settlements, industry and tourism. Human activities strongly increase the background levels of toxic trace metals such as mercury, copper, lead and cadmium in natural waters. Thus, the seawater quality plays very important role in well-being of human, animals and plants inhabiting the area. The quality of surface water within a region is influenced by both natural processes and anthropogenic activities. Marine water quality has become a matter of serious concern because of its effects on human health and aquatic ecosystems including marine life.

The Indian Coast

The Indian Ocean is the third largest of the four major oceans. It covers an area of 74 million sq. km which comprises about 20 % of the total area of water in the world. The ocean has been and remains the frontier of intercontinental trade. A large number of countries, India, are increasingly dependent on the Indian Ocean for their foreign trade and fishing industries. The future is expected to make the sea lanes of the Indian Ocean important not only to India, but also to the littoral states of the Indian Ocean that are dependent on the ocean for fishing, shipping and transportation. Recently study suggested that about 70 % of the total sea transport is ferried through Indian waters (Anon, 2003). Moreover, Asia's largest ship breaking yard Alang and fish landing site Veraval is also located along the west coast of India. Thus, the long coastal belt of India, which is known to be rich in fishery and mineral resources, is therefore, at high risk of a serious ecological imbalanced. India has a vast coastline of 7500 km along the mainland in addition to that of the Andaman and Nicobar Islands in the Bay of Bengal and the Lakshadweep Island in the Arabian Sea (Nayak, 2005). The Indian coast has a large variety of sensitive ecosystems like lagoons, sand dunes, coral reefs, mangroves, sea grass beds and wetlands (Ingole, 2005). These coastal habitats are considered highly productive in terms of biological production. Some of these areas have been act as spawning and nursery ground for commercially important fishes, molluscs, crustaceans and various other species that constitute the coastal fisheries.

The coastal stretches of Gujarat have several industries, which are based on salt as raw material. The salt pan activities not only provide livelihood for large number of unskilled workers but also provides raw material for several such chemical industries. Various industries on the Gujarat coastline like the Birla factory in Porbandar, GHCL in Sutrapara, LNT and Cement factories in Kodinar, Bhavnagar and Jaffrabad and various other Gujarat chemical industries on the Saurashtra-Kachchh coastline have been dumping millions of liters of industrial effluents and toxic wastes into the coastal waters every day, as they have no treatment plants. For example, there are four soda ash industries in Saurashtra producing more than 60 percent of the country's total production. One factory or another at one time releases effluents with more ammonia than maximum permissible limits. Veraval is one of the important port cities located the western coast of Gujarat. In addition to this, load of pollution generated from the operation of boats and vessels, the domestic wastewater generated from the Veraval town is being discharged into the fishing harbour area without collection/treatment and also the effluent generated from the 45 fish processing industries located in the nearby GIDC also being discharged in to this fishing harbour area. All these sources of pollution from different spheres are contributing the load of pollution in fishing harbour area and subsequently contaminating the nearby coastal waters. An additional, about 14 fish processing industries are also located in Mangrol and Dwarka.

The present study was undertaken to set up an innovative trend of monitoring of the human-nature interaction and its effect on the natural system to set up the openings of the future study on this tract at this area. In this context, a detailed study on the Saurashtra coastline, one of the biggest one in India desired a detailed monitoring to work out the present status of the ecosystem, the threats mounting and impending, natural resistance and adaptation in response to the pressure and a possible negotiation to the neutralize the harsh condition to offer a better tomorrow. The present study deals with the biodiversity and man-made pressure on the coastal health of the rocky intertidal macrofauna in four different stations along the Saurashtra coastline. With a view to assess the status of the few key species of intertidal mollusca, the heavy metal contamination of the coasts and the interaction between the fauna and anthropogenic activities were investigated. The Western coastal belt of India, these days is considerably being exploited heavily by various kinds of Industries. This study revealed how this is affecting the ecosystem of this area.

Aims, Objectives and Hypotheses

Research Aims

In view of the aforementioned understanding of the subject, the aims of the study is to prepare a baseline database of the intertidal macrofauna and the present ecological status of few prominent invertebrate macrofaunal species around anthropogenically influenced shores along South Saurashtra coastline.

Research Objectives

The objectives of the study can further be elaborated into the following subdivisions:

- To study the intertidal habitats at the selected site.
- To understand the biological nature of the intertidal areas (habitat) around the research site.
- To provide a baseline database of the coastal intertidal macrofauna around the selected locations.
- To identify the type and degree of anthropogenic activities those involve in terms of industries, fisheries, port activities, effluent and sewage disposal etc. in the coastal area under study.
- To estimate the attributes of population ecology like abundance, density and frequency of some prominent species of that area in order to understand the present ecological status in terms of space and time.

Hypotheses

Four principal hypotheses were tested in this work which was designed in Null form:

1. There will be no significant spatial and temporal variations in the gross macrofaunal diversity between the selected study area and the rest of the South Saurashtra Coastline.
2. The population density or abundance will not be significantly influenced in the spatial condition when placed against the time scale.
3. The ecological pattern of the macrofaunal population will not be influenced by the time scale.
4. Spatial distribution of the intertidal organisms will not be responsive against the pressure made on the system by anthropogenic activities.

Chapter - II: Review of Literature

Coastal areas can be regarded as the interface between three habitable media namely earth, air and sea. Coastlines have always been the “subject of fascination and study” (Raffaelli and Hawkins, 1996), with natural historians’ first recognizing areas dominated by certain species as early as 1832. In the 1890’s ecologists began to realize the potential interest of the Intertidal zone, taking specimens into the laboratory to carry out experiments (Benson, 2002). Ecologists are faced with the prospect that the relative importance of different factors influencing ecological systems will alter from place to place and time to time, depending, for example, on recruitment events (Underwood and Denley, 1984; Keough and Black, 1996), disturbance regimes (Thrush et al., 1994) and other factors that influence the heterogeneity of the environment (Barry & Dayton, 1991; Peterson, 1992). Many general reviews on biodiversity are available including the global diversity assessment (Huston, 1994). But there is scarce or no concise synthesis of marine biodiversity available in relation to conservation needs, only specific reviews as coastal zone biodiversity (Ray, 1991).

The principal interest to the marine ecologists is the relative importance of biotic interactions (predation and competition) and abiotic factors, such as disturbance, in structuring communities (Menge and Sutherland, 1987; Menge and Farrell, 1989). The marine intertidal zone has been used as a model system for many studies examining these factors (Connell, 1961; Paine, 1980; Menge et al., 1994, Berlow, 1997). Predation which including herbivorous by invertebrates is an important factor affecting the structure of many intertidal communities. Similarly, abiotic disturbance and resulting succession are known to be important in structuring communities (Dayton, 1971; Berlow, 1997). Rocky shores are more variable than other coastal habitats. Depending on the local geology they may range from steep, overhanging cliffs to wide, gently shelving platforms from smooth uniform slopes to highly dissected irregular masses or even extensive boulder beaches (Lewis, 1972). Rocky shores are rich in invertebrate fauna and provide a multiple range of habitats for a variety of organisms belonging to almost all invertebrate phyla. The ecological importance of the littoral zone in marine ecosystem is widely recognized.

The change in environmental factors due to the tidal cycle is one of the most extreme of any marine environment. With a few exceptions, marine organisms are the main inhabitants of the assemblages in the intertidal zone (Bulleri et al., 2005; Davidson, 2005; Nakaoka, et al., 2006). While factors such as desiccation, overheating, freezing, and exposure to high-energy wave impacts can pose serious problems to marine organisms, the intertidal zone also is often a refuge from competitive biological interactions and predation (Beyst, et al., 2002). The dynamic interplay of physical and biological factors in the intertidal zone is thought to be the reason for high biodiversity in rocky intertidal temperate communities that can rival or exceed subtidal communities (Suchanek, 1994). The rocky shores of the North Pacific are particularly rich in algal and faunal diversity (Zacharia and Roff, 2001; Okuda et al., 2004). In most hard-bottom intertidal regions, macroalgae add a major structural component that can serve as habitat for associated invertebrates (Hayward, 1980). Macroalgae offer substrate, shelter and food (Duffy and Hay, 1991; Iken, 1999) as well as protection against wave surge and desiccation (Molina-Montenegro, 2005) to associated fauna.

The populations inhabiting the rocky intertidal have been considered as open due to larval transport and recruitment from separate populations (Underwood and Fairweather, 1989; Menge, 1991; Small and Goslling, 2001). This openness produces a variable recruitment, which combined with diverse abiotic factors create a spatio-temporal mosaic from the local to the regional scale (Underwood, 1999; Jenkins et al., 2001). The variability found in populations inhabiting the rocky intertidal may be due to different abiotic factors such as tidal regime, temperature, red tides, changes in sea level, storms, wave action, and fisheries (Underwood and Fairweather, 1989; Denny and Paine, 1998).

The littoral portion of the shore, as it is variably described, covers the area between the high and the low tides. The Intertidal zone reflects the sessile or sluggish nature of the common species. A greater range of environmental conditions characterizes the intertidal zone than any species can permanently withstand and still reproduce successfully. The ecological importance of the littoral zone in marine ecosystem is widely recognized. The significant role of invertebrate for the detection of long-term environmental effects has been corroborated in many studies using both soft and hard substrates (Rogers and Greenaway, 2005).

Vertical zonation of plants and animals in the intertidal zone is conspicuous feature of all sea shores (Stephenson and Stephenson, 1972). Most early hypotheses about the causation of this zonation emphasized the tide as a primary factor. Connell (1972) reviewed the evidence that not only the physical factors probably set the upper limits of species distribution but, also, that biological interactions with other competitors and natural enemies may affect the lower limit of distributions. Conditions for growth and survival of organisms in either the presence or absence of biological interactions are often better lower than higher on the shore (Sutherland, 1975; Frank, 2004).

The amount of literature concerning distribution patterns of rocky shore organisms is vast. Classical descriptive works include the universal scheme of zonation proposed by Stephenson and Stephenson (1972), the extensive study of zonation pattern on the British Isles by Lewis (1964), and the similar approach for the Mediterranean by Peres and Picard (1964). Simultaneously with the descriptions of pattern of distribution (Russell, 1991) marine ecologists started to investigate the influence of physical and biological factors on marine intertidal communities (Underwood, 1981). Experimental approaches to understand the functioning of rocky shores encompassed disturbance and succession, competition, grazing, predation and recruitment fluctuations (Jenkins, et al., 1999). An extensive literature in this line has been put forward by Raffaelli and Hawkins (1996).

The spatial distribution of organisms provides information on both organism-organism and organism-habitat relationships (Findlay, 1981; Underwood and Chapman, 1996). If individuals or species interact, or if their environment is not homogeneously suitable, their distribution will bear some imprint of this. As such, identifying spatial distribution patterns is an essential step towards understanding the processes structuring ecological communities and the scales at which these processes act (Underwood and Chapman, 1996). The deep sea benthos is notoriously species-rich at small spatial scales, and small-scale patchiness in species distributions has been the basis for hypotheses on mechanisms maintaining this high local diversity (Snelgrove and Smith, 2002). However, there is a general paucity of data on species small-scale distribution patterns, resulting in limited empirical support for any of these hypotheses. Indeed, most studies of deep-sea, soft-sediment communities have mainly concentrated on mesoscale (meters and kilometres) changes in abundance and diversity, while knowledge about spatial structure at the small scale is scant (Rice and Lambshead, 1994).

The limited available research on the small-scale spatial patterns of deep-sea macrofauna (Volckaert, 1987), harpacticoid copepods (Eckman and Thistle, 1988) and foraminiferans (Bernstein and Meador, 1979) generally suggest that abundances of sediment-dwelling macrofauna and meiofauna are significantly affected by processes operating at horizontal scales smaller than 10 cm. However, due to the low numerical abundances frequently encountered in the deep sea, analyses often showed little significant departures from random dispersion, significant spatial patterns having mainly been detected for a few species of polychaetes and harpacticoid copepods (Eckman and Thistle, 1988). At intermediate scales, patterns of larval dispersal with coastal currents can greatly affect population and community structures of benthic organisms at the scale of tens to hundreds of kilometers (Morgan, 2001; Underwood and Keough, 2001). Clarification of relative importance of multiple factors operating at different scales and of their interacting effects is crucial and challenging for understanding community processes and their resultant biodiversity patterns (Nakaoka and Noda, 2004).

Nakaoka et al. (2006) studied on a major goal of ecology is to understand the factors contributing to the distribution and abundance of organisms at a variety of spatial scales. As broad scale questions are increasingly dominant in conservation and management, marine ecologists have been pressed to examine linkages between patterns and processes operating at spatial scales larger than individual sites (Schiel et al., 2004; Schoch et al., 2006). In marine systems, this ‘scaling-up’ has resulted in a significant conceptual shift in our understanding of the connections among populations and communities and the importance of benthic–pelagic linkages. Benthic communities are inextricably linked to the oceanic environment through the delivery of food, nutrients. The oceanographic processes driving the delivery of these constituents span large spatial scales and thereby connect distant onshore communities (Schiel, 2004).

Underwood et al. (1983) studied the fluctuations in abundance, distribution, seasonal community dynamics and primary productivity of macro-organisms and macrophytes in relation to environmental variables from different rocky intertidal shores of

California and South Wales. The distribution of algae and invertebrates on rocky shores in the northwest Mediterranean, Italy was carried out by Menconi et al. (1999). Boaventura et al. (2002) investigated the tropical structure of macrobenthic community on the Portuguese coast. The significant role of invertebrate for the detection of long-term environmental effects has been corroborated in many studies using both soft and hard substrates (Rogers and Greenaway, 2005). There have been studies on marine benthic communities in the Arabian Gulf, particularly those of the intertidal coastal are of Saudi Arabia, Kuwait, Bahrain and UAE (Jones, 1986). The general features of the intertidal and subtidal macrobenthic fauna of western and northern gulf are well documented (Jones and Richmond, 1992). The shelves and littoral zones below the level of ice scour are dominated by dense communities of suspension feeders. Octocorals are one of the major components of these communities in terms of both abundance and diversity in some Antarctic places (Starmans et al., 1999).

The number of species and variability in occurrence of the fauna is determined by their ability to colonize and withstand the changing conditions of this habitat a local scale and their capacity to maintain interspecific interactions (Lewis, 1964; Connell, 1972; Stephenson and Stephenson, 1972; Little and kitching, 1996; Raffaelli and Hawkins, 1996). In many cases, rocky intertidal habitats are affected by the prevailing hydrographic conditions, especially in areas influenced by upwelling (Menge et al., 1997; Menge, 2000). Thompson et al. (2000) suggested that rocky intertidal shores are nursery and feeding areas for a number of species of crustaceans, fishes and other invertebrates, which are interconnected with adjacent terrestrial and marine ecosystems. The populations inhabiting the rocky intertidal have been considered as open due to larval transport and recruitment from separate populations (Underwood and Fairweather, 1989). This openness produces a variable recruitment which combined with diverse abiotic factors create a spatio-temporal mosaic from the local to regional scale (Jenkins et al., 2001). The variability found in populations inhabiting the rocky intertidal may be due to different abiotic factors such as tidal regime, temperature, changes in sea level, storms, wave action and fisheries (Pulliam, 2000).

There have been studies on marine benthic communities in the Arabian Gulf, particularly those of the intertidal coastal are of Saudi Arabia, Kuwait, Bahrain and UAE (Jones, 1986). The general features of the intertidal and subtidal macrobenthic fauna of western and northern gulf are well documented (Jones and Richmond, 1992). The Antarctic benthos is not only rich in terms of species; biomass values are also quite high, comparable to temperate and tropical ecosystems, though distribution tends to be much patchier (Brey and Clarke, 1993).

In India, Seshappa (1953) and Kurian (1953) were the first to carry out detailed studies on the bottom fauna off Madras, Malabar and Travancore. Since then, a number of investigations have been carried out along both the east and west coasts (Ganapati and Lakshmana Rao, 1959; Radhakrishna and Ganapati, 1969; Kurian, 1971; Damodaran, 1973; Ansari et al., 1977; Harkantra et al., 1980, 1982; Parulekar et al., 1982; Raman and Adiseshasai, 1989; Raut et al., 2005). Studies on benthos along the shelf region of northwestern India are limited to the studies of Neyman (1969), who studied the benthos of the shelves in the northern part of the Indian Ocean. Other works in the northwest coast of India include those of Parulekar and Wagh (1975), Parulekar et al. (1976), Harkantra et al. (1980), Joydas and Damodaran (2001), and Joydas (2002).

In addition, Parulekar et al. (1982) studied the benthos of the Indian seas. However, another work has been done by Varshney et al. (1988), who studied the macro-benthos of very-near-shore depths (5–20 m) off Versova, west coast of India and Kundu et al. (2009) at Bay of Bengal. One of the important characteristics of benthic fauna along coast of India is their wide seasonal and regional variations (Achuthankutty et al., 1978; Murugan et al., 1980; Divakaran et al., 1981) and their influences on the abundance of living resources and energy transfer among organisms in the aquatic community (Chandran et al., 1982; Parulekar et at., 1982).

In order to develop conservation strategies for the protection of biodiversity in these coastal ecosystems, more research on basic marine biodiversity patterns and community structure should be conducted (Olsgard et al., 2003). Molluscan communities are effective indicators of overall ecosystem health and species diversity (Rittschof and McClellan-Green, 2005), making them ideal study organisms of conservation and biodiversity studies. Gastropods are of particular interest, not only due their importance in human culture but also because they fill integral ecological roles, from grazers to scavengers and carnivores (Sturm et al., 2006). They inhabit a range of diverse habitats, from backyard gardens to the deep sea (Suominen et al., 2003; Sturm et al., 2006).

Even though the relationship between the diversity of species assemblages and the complexity and heterogeneity of the habitat is well known, ecologists have difficulty understanding the real underlying processes (Beck, 2000). For instance, numerous studies of the effects of habitat structure on species assemblages have not indicated that complexity or heterogeneity clearly enhances diversity, as might be expected theoretically (Guichard and Bourget, 1998). These ambiguous or even contradictory results have been attributed to such factors as the choice of a single observed taxonomic group, premature successional age of the studied assemblages, or an inappropriate observation scale (Chittaro, 2002). The scale of observation is very important, as suggested by Bishops et al. (2002). Another complication is the different meanings given to the same term in the literature relative to the effects of habitat structure on species assemblages (Beck, 2000).

The similarity indices measure the similarity level of two communities. According to Washington (1984) this method, which could be a very useful tool in monitoring water bodies, requires a non-polluted reference environment. The different aims of chemical and biological monitoring and the advantages and disadvantages of biotic and diversity indices have been discussed by De Pauw and Hawkes (1993) and Ravera (1998). There is a very rich literature on biotic and diversity indices, but relatively few comparisons of these methods have been made (Cao, 1996).

Phylum Mollusca are the second most diverse group of marine macro invertebrates. Marine molluscs constitute an important and one of the dominant phyla of the rocky intertidal coast of India. The littoral benthic organisms as a whole and the molluscs, in particular play an important role in the local marine food chain (Barnes, 1974). Although most gastropods are motile, their comparatively slow locomotion prohibits movement into and out of the intertidal zone over the relatively short period of tidal range. As a result they constitute one of the many groups whose spatial distribution typically consists of well-defined portion of the intertidal zones. From India, a total of 3271 species of molluscs are known to occur, belonging to 220 families and 591 genera, of which 1900 are gastropods, 1100 bivalves, 210 cephalopods, 41 polyplacophorans and 20 scaphopods (Appukuttan, 2008).

The shells of molluscs are among the most abundant biogenic minerals. In the past five decades, shells have drawn much attention from scientists in material science, nanotechnology, and biology for their unique physical and biological properties (Fritz et al., 1994; Kamat et al., 2000; Rubner, 2003; Tang et al., 2003). Marine molluscs have adapted themselves to live on almost all types of bottom. Although most of the species are free living (Krishnakumari et al., 2002), there are molluscs which prefer to attach to rocks, stones, shells or wood, some burrow (Souza and Gianuca, 1995), some bore into woods and rocks and some can swim freely such as squids and octopuses.

In the international market there is a good demand for molluscan products. In the far East countries molluscan products fetch higher prices (Korringa, 1976). Octopus, cuttle fishes, squids, oysters and mussels have a good market in European countries especially in Western Europe. Different species of gastropod are utilized as food, shells for ornamental purposes and operculum for cosmetic and medicinal use (Ramesh et al., 1990), as a diet for other animals like shrimps (Raghunathan et al., 2004), mother of pearl for the manufacture of buttons and wood in lays and becomes the significant external trade in various parts of the world like India, Indonesia, Thailand, Australia, Japan and U.S.A. The cowries are important in various fields, of which the most remarkable is their use as a medium of exchange (replacing the old barter system).

Shells of commercial value are described by Jones (1986) and Durve (1973). Ornamental shells, chanks and pearl oysters are the basis of an important industry in the south (Wafar, 1986; Silas et al., 1985). *Trochus niloticus* and *Turbo marmoratus,* are the most important molluscs collected for their shells and both species are collected in the Andamans for export (Silas et al., 1985). *Trochus* was over collected in the Andaman and Nicobar Islands in the 1920s when the Japanese were given licenses to collect (Rae, 1937). In 1976, 400 tons of trochus and 105 tons of green snails, *Turbo* were landed in the Andamans (Appukuttan, 1977; 1979). Nayar and Appukuttan (1983) give annual production as 400-500 tons of *Trochus* and 100-150 tons of *Turbo.* Shelling is licensed by the Revenue Department of the Andamans and takes place in seven defined zones; fishing grounds are leased to traders and royalties from the catch are collected by the government.

Variations in the distribution, abundance and size-structure of populations have been central themes in molluscan ecology (Kelaher and Cole, 2004). Such patterns of variation form the basis of studies aimed at elucidating important ecological processes (Raffaelli and Hughes, 1978), managing molluscan biodiversity (Eekhout et al., 1992) and detecting environmental change (Thrush et al., 2000). These patterns are, however, rarely simple because they are the product of numerous biotic and abiotic factors acting at a variety of spatial and temporal scales (Barry and Dayton, 1991).

Patterns of distribution and abundance have been well described for many marine molluscs, such as herbivorous gastropods (Hawkins and Hartnoll, 1983; Chapman, 1994), predatory whelks (Sagarin and Gaines, 2002), microgastropods (Olabarria and Chapman, 2001) and bivalves (Thrush et al., 2000; Beukema and Dekker, 2001). Generally, these molluscs vary at a hierarchy of spatial scales from cm to 1000s of km (Archambault and Bourget, 1996). In particular, large amounts of variation have been shown in the spatial arrangement of individuals separated by less than a meters and among patches of habitat separated by 100s of meters' along the shore (Olabarria and Chapman, 2001).

On a temporal scale, abundances of molluscs can also vary dramatically from season to season (Vaghela et al., 2010), year to year (Misra and Kundu, 2005) and over longer periods of time (Underwood 1999; Burrows et al., 2002). Few studies, however, have simultaneously evaluated temporal variation of molluscs at multiple scales (Underwood, 1997), with most focusing only on a single sampling frequency (e.g. monthly, seasonally or yearly sampling). In contrast to other molluscs, little is known about patterns of variation for chitons, despite their high abundance and diversity in many marine habitats (Boyle, 1977; Misra and Kundu, 2005). Previous research on chitons has focused predominantly on their reproductive biology (Currie, 1990) and behaviour (Chelazzi et al., 1983). More recent attention from experimental ecologists has, however, demonstrated that herbivory of chitons can strongly influence the benthic assemblages of intertidal habitats (Smith and Otway, 1997).

Sessile and mobile molluscs are an important and diverse component of natural intertidal assemblages around Sydney, with 20–30 species commonly found per 0.25 m^2 quadrate (Underwood, 1981). Oysters and mussels grow on large numbers on seawalls, often overgrowing other assemblages. They provide biogenic habitat for a suite of smaller animals and plants (Chapman et al., 2002). Limpets and snails are important structuring agents of intertidal assemblages (Underwood et al., 1983), controlling distribution of algae (Underwood, 1998), bulldozing small sessile animals (Denley and Underwood 1979), or consuming sessile and mobile prey (Fairweather, 1988).

Estimation of the production of each species in a food web is the key to formulating concepts of its dynamics (Burke and Mann, 1974; Denadai et al., 2004), which leads to the understanding of energy flow in communities. Molluscs are an important group in unconsolidated intertidal environments, where they have relatively high biomass. Bivalves outnumber gastropods on sandy beaches, but gastropods may be proportionally more abundant where large granules, such as rock fragments, are mixed with the sediment (Denadai and Amaral, 1999). There have been many investigations of the population structure of bivalves, mainly commercially important species (Salvador, 2001), but comparatively few studies have been done on gastropods (Noda, 1997).

Molluscan studies on the growth, reproduction and population structure were undertaken with reference to one particular species of molluscs. It is noted that initial work on ecological problems is related to description of organism inhabiting a particular shore. The seasonal changes in distribution, density, diversity and population structure of individual species of gastropods from different rocky shores have been studied by a numbers of authors (Underwood and Creese, 1976; Misra and Kundu, 2005). Population dynamics and biomass estimation study provide pertinent information about species richness, species composition, dominance and the size area relationship of organisms with the environment. In India very few studies have been undertaken on the population dynamics, species composition and biomass estimation of benthic organisms. Studies of molluscan populations and communities along the Mexican Pacific have historically focused on species of commercial interest (Rios-Jara et al., 2001), and the majority of these have been conducted on the continental shelf

(Landa-Jaime and Arciniega-Flores, 1998). There have been few investigations in the particular case of rocky shores, where most of the authors have carried out taxonomic works (Holguin-Quinones and Gonzalez-Pedraza, 1994; Sevilla, 1995; Reyes-Gomez and Salcedo-Vargas, 2002), and others have been concerned with the zonation, richness and species diversity of molluscs (Esqueda et al., 2000; Villarroel et al., 2000) and the different regions exposed to waves (Del Rio-Zaragoza and Villarroel-Melo, 2001).

Tegula viridula (Turra and Denadai, 2006) is an intertidal trochid gastropod that feeds on encrusted algae (Moreira-Filho, 1960), while *Morula nodulosa* is a small drilling muricid predator (Magalhaes 2000). The shells of these gastropods are frequently used by sympatric hermit crab species (Leite et al., 1998) and are also collected by local handicraftsmen for the production of souvenirs. These gastropods are commonly found in the intertidal and shallow sub-tidal regions along the rocky shores of the Sao Sebastiao Channel in southeastern Brazil (Denadai and Amaral, 1999) and may be important agents in structuring intertidal communities (Magalhaes, 2000).

In India, superior account on some molluscan resources of Andaman and Nicobar islands is available (Subba Rao, 1980; Tikader and Das, 1985; Tikader et al., 1986). Information on the distribution of chiton, strombids and conids came to light through the works of Rajagopal and Subba Rao (1974), Subba Rao (1977). Mumbai, the most industrialized city of India, was famous for its rich molluscan biodiversity in the past (Rai, 1931) from where 24 species of pelecypods and 90 species of gastropods were recorded (Subrahmanyam et al., 1949; Subrahmanyam et al., 1951). Many investigators have assessed physicochemical characteristics also and indicated the deteriorating condition of this habitat (Zingde and Sabnis, 1994; Govindan and Desai, 1980; Sabnis, 1984). Fernandes (1991) and Jaiswar et al. (2006) evaluated the impact of pollution on selected gastropods of Bombay by detecting the concentration of various pollutants in the animals from polluted and non-polluted areas. Venkataraman and Wafar (2005) studied overall coastal and marine biodiversity of India, Vaghela et al., (2010) studied the macrofaunal diversity and community structure at Gulf of Kachchh.

Benjamin et al. (2008) developed an ecosystem-specific, multi-scale spatial model to synthesize 17 global data sets of anthropogenic drivers of ecological change for 20 marine ecosystems. Their analysis indicates that no area is unaffected by human influence and that a large fraction (41%) is strongly affected by multiple drivers. However, large areas of relatively little human impact remain, particularly near the poles. The analytical process and resulting maps provide flexible tools for regional and global efforts to allocate conservation resources; to implement ecosystem-based management; and to inform marine spatial planning, education, and basic research.

A majority of these studies have investigated the impacts of human activities, such as trampling or food harvesting, which have been shown to be detrimental to a large number of species including seaweeds (Bally and Griffiths, 1989; Schiel and Taylor, 1999), seagrasses (Zedler, 1978; Ambrose and Smith, 2004), barnacles (Zedler, 1978; Ghazanshahi, et al., 1983), limpets (Pombo and Escofet, 1996; Kido and Murray, 2003; Roy et al., 2003), sea stars (Ghazanshahi, et al., 1983; Ambrose and Smith, 2004), octopuses (Ghazanshahi, et al., 1983), snails (Roy, et al., 2003), crabs (Murray, et al., 1999), and bivalves (Smith and Murray, 2005).

Unnatural anthropogenic disturbances have exponentially increased in areas around the world, with negative effects on habitat biodiversity (Fahrig, 1997). These man-made disturbances can drastically change the composition of both the physical habitat and the organisms living within it, and habitat fragmentation is the primary cause of local and global extinctions and biodiversity loss across all taxonomic groups (Nichols et al., 2007). Climate change is another anthropogenic threat, although the negative effects it causes on habitats are more subtle. Increased greenhouse gases have caused more heat to be trapped within the atmosphere and have changed climatic patterns (IPCC, 2007). The frequency and intensity of extreme weather conditions such as hurricanes, floods, heat waves, draughts, and tropical cyclones has and will continue to increase (IPCC, 2007).

Anthropogenic activities are generally considered to be responsible for a decline in the biological diversity of rocky intertidal habitats along the southern California coast (Roy et al., 2003). Roy (2007) was to use historical data collected over the last century to construct a long-term perspective that can be used to quantify the ecological consequences of anthropogenic impacts on rocky intertidal molluscan species and populations in the southern California. Anthropogenic effects on marine invertebrate diversity and abundance was studied by Alan J. K. and Amanda M. B. (2005) along the sandy intertidal area off Western Australia. Settlement, industry, increased fishing pressure, pollution, reclamation of wetlands and mangrove areas and deforestation are causing increasing pressure on the coastal environment (Ahmad, 1987; Silas et al., 1985), although it has also been suggested that ecological deterioration and pollution is not yet widespread (Ahmad, 1987).

Coastal urbanization is an increasing problem as human populations continue to grow, people are becoming more urbanized (Botkin and Beveridge, 1997; McKinney, 2002) and, with greater affluence and leisure time, many coastal habitats are becoming more attractive for residential development and recreation (Vitousek et al., 1997; Connell and Glasby 1999). Many of the fastest growing cities are on the coast (Pickett et al., 2001, 2004). Industrialization on the shore of the rocky coast came out during the past few years with an obvious result of decline in marine population and in coastal health status. Food preference and association study was carried out on the prominent intertidal gastropods of this zone viz. *Cellana radiata*, *Chiton* sp., *Turbo cornatus*, *T. intercoastalis* and *Trochus* sp. The two snails, *Turbo intercoastalis* and *T. cornatus* (Gastropoda, Turbinidae), have been reported to be widely used as a food item in tropical and subtropical western Pacific regions, as well as a material for shell craft in Korea, China, Japan and Europe for hundreds of years. In India the snails are widely used for the same purpose (Sarvaiya, 1977). Over the past twenty years, the populations of the snails along the Saurashtra coast, the West coast of India have markedly decreased because of heavy over fishing (Malli, 1993). So, with the increasing human population and their demands, the threat is mounting on these organisms to stretch out for a wider adaptability for food stuff and habitat to avoid predation. All the marine pollution must originate from one or the two sources, either the land or the sea. Of course, marine pollution is defined as a human activity and humans are land inhabitants and so it might be scientifically correct to assert a land base origin for all marine pollution. These kinds of human impacts generally alter the structure and function of marine aquatic ecosystem by changing the species compositions of community and also affecting nutrient cycle (Nemerow, 1985) and ultimately threaten equilibrium of planet’s biosphere. It has been predict that perhaps a quarter of the earth’s total biodiversity is at serious risk of extinction during next 22 to 30 years because of the sever impacts of pollution on marine environment (Ravan, 1988).

Human influences are reflected as both acute and chronic effects over various temporal and spatial scales and can ultimately lead to broad-scale loss of productive habitats and altered or impaired community structure and function. Gray (1997) provides an excellent review of threats to coastal systems, which include habitat loss, global climate change, effects of fishing, pollution, species introductions and invasions, water shed and physical alterations of coasts, tourism and marine litter. In some cases the impacts of fishing activities are restricted to changes in target species size and abundance, either with no observable change in community diversity or species richness (Watson, et al., 1996), or with no change in richness but changes, including increases, in diversity due largely to changes in evenness (Rice, 2000). In other cases fishing activities have led to declines in richness and diversity through extirpation of target species (Gislason, et al., 2000). The structural complexity of a habitat has often been invoked as an important factor influencing the diversity of associated communities (Huston, 1994), a more complex habitat providing a wider range of niches and thus a higher number of species that can potentially occupy that habitat within a given area (May, 1972).

The worldwide increase in sediment load in coastal areas as a consequence of anthropogenic activities has increased interest in the impact of sedimentation on rocky shore ecosystems (Newell et al., 1998). Natural factors such as wind-driven waves may also influence temporal fluctuations of sand movement in coastal areas (Anderson and Meyer, 1986, Lund-Hansen, 1991). In fact, periodic inundations by sand as a result of coastal currents or the action of storms are a very common abiotic disturbance of rocky coasts throughout the world (Trowbridge, 1996). Sediments are added to a rocky coast and are redistributed as a function of sediment characteristics, hydrodynamic conditions, bottom heterogeneity and biological factors (Hiscock, 1983). These factors operate over a wide range of spatial and temporal scales. Thus, while at large spatial and temporal scales sediment deposition may be relatively predictable, depending on the source and magnitude of sediment loads, at small scales, patterns may be highly heterogeneous and unpredictable (Airoldi and Virgilio, 1998). The importance of sediments as a major source of spatial and temporal heterogeneity for rocky coast organisms has only recently been fully recognized (Airoldi, 1998). Sediments may occur as a thin stratum, or form deposits from a few to tens of centimeters thick. Depending on local hydrodynamic and topographic conditions, they may accumulate locally in crevices or be trapped in algal turfs, or be resuspended and transported above the substrata (Airoldi, 2003). Despite the extensive body of literature, there are few direct observations and experiments to investigate the effects of sedimentation on the organisms and assemblages inhabiting intertidal rocky shores (Prathep et al., 2003, Zardi et al., 2006).

Certain chemicals, for instance, make some animals more sensitive to heat or become more toxic at higher temperatures (Sokolova and Lannig, 2008; Patra et al., 2007; Schiedek et al., 2007); clearly those pollutants would be important to target in areas expected to see an increase in maximum temperatures. Changes in rainfall patterns are expected to increase the nutrient loads in some coastal areas. The majority of heavy metals (copper, tin, mercury, cadmium etc.) enter the marine environment through natural pathways such as volcanic activity and erosion of ore-bearing rocks. Human inputs include sewage, industrial discharges and urban runoff. Plants and animals vary widely in their ability to regulate their metal content (Clarke, 2001). Most can tolerate a limited range and those metals that cannot be excreted from the body bioaccumulation over time. Heavy metals can affect the growth, reproduction and genetics of key species on the rocky shore (Crowe et al., 2000). Clarke (2001), found heavy metal contamination to be more prominent in sheltered areas, where metals have higher residence times, allowing their concentration. Castilla (1996) found changes in community structure as a result of rocky shores being impacted by copper mine tailings. Al-Ghadban et al. (2007) were studied on the environmental stress of Kuwait's coastal area due to the 1991 oil slick. This was accomplished through the implementation of several activities such as: the geomorphology and sedimentology of the coastal area; the distribution and toxicity of organic contaminants; the biological characteristics (oceanographic, algal communities, macrofauna) of the intertidal area; and the state of the main coral reefs communities. Rapid urbanization, industrialization and population growth have been the major causes of stress on the environment leading to problems like human health problems, eutrophication and fish death, coral reef destruction, biodiversity loss, ozone layer depletion and climatic changes (Bay et al., 2003; Sadiq 2002). Due to these activities coastal zone, has given rise to waste discharges in some major rivers, which is responsible to degrade the estuarine and coastal waters (Zingde and Desai, 1987). In the east coast of India, increased metal concentration in the coastal waters of Pondichery as reported by Govindasamy and

Azariah (1999) was as a result of the effluent discharges of nearly 16 major and minor industries.

The relationship between Macrobenthic community structure and heavy metals contamination has been studied by previous researchers (Dauvin, 2008). Rygg (1985) studied the relationship between species diversity in benthic fauna communities and concentration of heavy metals (Cu, Pb and Zn). He found a strong negative correlation between species diversity and copper concentration. Hall et al (2000) studied the effects of metal contamination on macrobenthos community in estuaries appeared to respond positively to large reductions in the inputs of contaminants. Warwick (1993) investigated the effects of metal contamination on the intertidal macrobenthic assemblages of the Fal estuary and concluded that of all the environmental factors, heavy metal concentration correlated strongly with composition of biological communities.

Investigations on the harmful algal blooms, metal levels in marine organisms, bacteriological and toxicological studies and organic and inorganic pollutants supported evidences to marine pollution in the Bay (Pan and Rao, 1997; Bu-Olayan and Thomas, 2001; Bu-Olaya et al., 2001). Several investigators observed metal concentrations in aquatic macro benthic organisms to be a better indicator than ambient (water) metal concentrations (Brandt, 1995). Studies revealed oligochaetes as an indicator to organic and industrial pollution (Carr and Hiltunen, 1965; QiSang and Erseus, 1985). Earlier observations showed benthic organisms to be highly sensitive to environmental stress due to trace metal pollution (Stoykov and Uznovz, 2001). They also noted anthropogenic pollution influenced by sedentary benthic organisms.

Chapter - III: Materials and Methods

3.1. Study area

The Indian coastline is about 7517 km long, 2000 km wide economic exploitation zone, the Bay Island of Andaman and Nicobar, and the atoll Island group of Lakshadweep, India harbors a vast extent of coast and marine habitat. The coastline comprises of headlands, promontories, rocky shores, sandy spits, barrier beaches, bays, marshy land and offshore Islands. According to the naval hydrographic chart, the Indian mainland consist nearly 43 % sandy beaches, 11 % rocky coast and 46 % mud flats and marshy coast. The Indian coastline supports almost 30 % of its human population being dependent on the rich exploitable coastal and marine resources.

Among the eight maritime state of India, Gujarat, situated on the western coast of India, has longest coastline about 1650 km long shore which is comprises about 22 % coastal stretch of the total coastline of India. Gujarat coastline consist 28 % sandy beach, 21 % rocky coast, 29 % muddy flats, 22 % marshy coast. Gujarat coast could be broadly described in to four regions viz. the Gulf of Kachchh, the Saurashtra Coast, the Gulf of Khambhat and the South Gujarat Coast. Among that Saurashtra is a region located south-western part of Gujarat, which is an arid peninsula and also called as Kathiawar. Saurashtra coast occupies a total stretch of 865 km., which is situated between two Gulfs encircled by the open sea. The continental shelf is vast, varying in width from 58 to 191 miles, of the coast of Saurashtra. With the gentle gradient the littoral zone is 0.5 to 1.5 km wide and covered with loose calcareous sand. Long shore currents, high wave energy with surf action and tides generally low in the range of 2 to 3 m characterized the coastline.

The south coast of Saurashtra from Dwarka to Kodinar segment stretches for about 250 km with smooth and sandy beaches. The beaches are usually calcareous and dominated by bio-clasts, the consolidated ancient equivalent of these biogenic sands are famous milliolite rocks. The milliolite underline the beach sands and occur as cliffs, wave cut platforms and submerged dunes, all along the shoreline indicating quaternary sea level fluctuations. The shoreline is straight and consciously rocky platform backed by sandy beaches.

3.2. Study Localities

Before the selection of study sites, locations of the sampling sites were selected according to a preliminary study of the coastline in view of different anthropogenic pressure on coastal area. Now a day's especially Saurashtra coast is being hot-spot for various mega industries, fishery related opportunities and further more tourism is also one of the related problems on the coastal zone of Saurashtra peninsula.

For present investigations, four different sites were selected along the South Saurashtra coastline off Arabian Sea, viz. Dwarka, Mangrol, Veraval and Kodinar (Plate 1). Each of these sites was chosen because they are accessible, on the open coast, and all these sites are influenced by the direct pressure of humans and pollutants from both harbors and terrestrial sources. The selected location of Saurashtra coast was surveyed extensively to monitor the coast characteristics, from both physical and biological approach.

3.2.1. Dwarka

Dwarka (22^0 13' N, 68^0 58' E) is situated on the west coast of India and a major pilgrim town owing to that it is also be a tourist place on the coastal area. It is nearest about Okha port which is well known as entry to western India and Gulf of Kachchh (GoK), around 175 km west of Veraval and around the northernmost corner of the Kathiawar peninsula. There are small scales fishing industries also available. The local community mainly depends on the tourism and fishing related opportunities. The total length of the sampling site was about 1.5 km.

3.2.2. Mangrol

On the other hand, Mangrol (21^0 07' N, 70^0 07' E) is a small hamlet and important harbor around 50 km west of Veraval with predominantly fisherman population. There are many small scale fisheries industries located along the coastline and it exports to many other countries. It having a proper landing place included all infrastructure facilities such as storage of catch, ice factories, repairing of boats and engines etc. The total length of this area is about 2 km. The local communities which live nearest about the coastline mainly depend on the fishing related opportunities.

3.2.3. Veraval

Veraval (21^0 35' N, 69^0 36' E) is one of the largest fish landing site of India situated around 35 km east of Mangrol, surrounded by a large chemical factory, a medium scale cement factory, number of small to medium scale industries and fish processing units. It involves port activities like transport, boat manufacture and receive waste from different sources. In addition to that, the area, being one of the most developed spot from industrialization point of view, is a hot spot for both heavy and small scale chemical industries. The area favors the fish processing industries too due to its proximity to the landing centre and easy supply of the raw materials. The total length of the study area is about 3 km.

3.2.4. Kodinar

Kodinar (20^0 41' N, 70^0 46' E) is a small town, situating southeastern part of Junagadh district, on the southern coastal region of Saurashtra peninsula. Tourists find ample places to visit in Kodinar and its nearby region. Here Gujarat Ambuja Cement Group has established its flagship cement factory and the company have also developed the port of Muldwarka. It is also well-known for the sugar factory, which is situated near about the coastline and also minute level of fish catching unit located near the selected site. Total length of the selected coastal stretch of the sampling site is about 1.5 km. The coastal area between Kodinar and Veraval is fast emerging as an industrial hot-spot and few mega industries are already in operation.

3.3. Study Period

The study survey was made from November 2007 to August 2009. During this period, each sampling sites along Saurashtra coastline were survey regularly for the macrofaunal diversity for qualitative assessment. The monthly data were collected for population ecological study during September 2008 to August 2009. Simultaneously, sea water samples were also collected for heavy metal analysis. The monthly surveys were summed up to four seasons viz., winter (December to February), summer (March to May), monsoon (June to August), post monsoon (September to November). During this study, it was also observed and note down the different anthropogenic disturbance on the coastal zone.

3.4. Coast characteristics

The Saurashtra shoreline is straight and conspicuously rocky platform backed by sandy beaches and dune ridges and occasionally cut by river or creek; where marshes are present. Generally the sediments are of carbonate sands. The rocky portion is generally formed of rocks of miliolite and laterite stone. Extensive limestone deposits are seen to occur in the coastal areas of Saurashtra. Rocky shores are rarely smooth slabs of rock. The intertidal belt is interspersed with many tide pools, puddles, crevices and small channels. The upper portion of the intertidal belt is generally covered with an admixture of silt and sand mixed with pieces of broken shells. Depended upon geology they will be crossed with cracks, crevices and pools. Hard rock like granite provides a more secure anchorage for plants and animals than the soft rocks, such as sandstone or chalk. The seabed is comprised of natural rock formation, which is covered with densely grown seaweeds. Thick deposition of sand also noticed in the small channels. On the sea front, the intertidal zone where the sea and the shore are pitted against each other is a unique habitat. The sequence of alternating tides result in the inevitable submergence and emergence of this habitat. The sandy beach gradually slopes into the rocky intertidal belt from landward side. The intertidal area is mostly spongy calcareous or spongy rocky substratum and the substratum of the shore area is of hard rocky.

3.5. Intertidal Zonation

Conditions on the Intertidal zone change, becoming wetter or drier, more or less exposed, more or less steeply sloped etc. as one moves around. These changes influence the composition, abundance and distribution of the population (Lewis, 1972; Prescott, 2006). Intertidal organisms are subject to a vertical gradient of increasing stress with increasing exposure to air higher on the shore (Crowe et al., 2000). This leads to increased abundance within zones where conditions are favorable to species survival; abundance decreases outside of this zone as the physical environment becomes less suitable. In 1949 the ecologists Stephenson and Stephenson devised a classification scheme of zonation of all rocky shores, where they distinguished four major zones. For the zonal study intertidal area was divided in to three major littoral zone viz. upper littoral zone, middle littoral zone and lower littoral zone, as per the sampling area accessibility.

3.6. Sampling Procedure

3.6.1. Sampling Method for Macrofaunal Diversity

The intertidal zone of each sampling sites were surveyed regularly on monthly basis and all the macrofauna and flora encountered were recorded properly. Extensive photography was employed for the identification of the animal species with the identification keys, literature available in the form of books, journals, reports and with extensive use of internet. The complete study was conducted in a non-destructive manner in which the organisms were disturbed to the bare minimum, let alone killing any. Once the organisms were identified, during the successive surveys just the record of the encounter was made. However, few algal samples were collected and stored immediately in 10 % formaldehyde. They were then brought to the laboratory and washed in running tap water, and then it was subjected for temporary herbarium preparation. During the study, all sampling sites were frequently surveyed at regular intervals during the lowest tides. All intertidal macrofauna and algae observed were recorded properly and later classified systematically. Thus animals under various phyla were recorded and checklist was prepared.

3.6.2. Sampling Method for Population Ecology

Transect and Movement

Transect sampling is one of the most widespread ecological techniques for sampling both plants and animals. The structural attributes of the intertidal fauna were studied by transect method (Misra, 1968). Gonor and Kemp (1978), Littler and Littler (1985), and Creese and Kingsford (1998) provide good previous accounts of non-destructive sampling methods for quantifying the abundances of intertidal populations which were followed in this study. Foot transect method was primarily used for generating the population database. The main problem in using any other method like belt transect as that all these methods would come out with the result of avoiding a major proportion of the area. The greatest advantage of foot transect method was that it took the maximum available ground into consideration. At all the sites, criss-cross direction was followed to cover the maximum exposed area on the intertidal belt. The visits were made at the lowest tides of the months.

Quadrate size and number

Quadrates are extensively used for sampling in all branches of ecology and many approaches are available (Greig-Smith, 1983). Quadrates of 0.25 m^2 were laid while following an oblique direction covering maximum area at almost regular occurrence on the preferred intertidal belt. Quadrate frequency was determined on the basis of the total length of the intertidal area along the sampling site. At the each zone of sampling site, ten quadrates were used to be laid during the study period. Sampling used to be started with the start of the low tide and attempts were made to finish two sites within the stipulated duration of about four hours.

3.7. Study Species

The Molluscan species were selected on the basis of their occurrence through the study area. As these were found to be the most prominent one and their presence throughout the season, these organisms were selected. More to that, as they were reported to be non-migrant (Inter coast), so long selection of these would ensure a long term study on the same aspect. As the study area was purely a rocky one, so filter feeders and other such organisms those are usually selected were not taken into consideration to work with on these belt. A close look to the animals shows that these organisms were dominant in all the three zones. So, a detailed study on these could reflect the ecological status of the three zones. The selected animals are *Mancinella bufo*, *Conus miliaris*, *Trochus radiatus*, *Turbo coronetus*, *Turbo intercostalis*, *Nerita albicilla* and *Rhinoclavis sinensis*.

3.8. Seawater Sampling and Metal Analysis

Sea water samples were collected monthly from each sampling site of the study area. The locations for the collection of samples in a particular coast were fixed using global positioning system (GPS). Water samples were collected from directly from the surface in previously acid-washed glass bottle and stored in HNO_3. The sea water samples, analyzed for concentrations of the major trace metals were estimated using an Atomic Absorption Spectrophotometer (AAS). Data was presented in mg/l concentration. The water samples were analyzed for various trace elements based on the procedures described in APHA (1995), Trivedi and Goel (1986).

3.9. Documentation of Anthropogenic Impact

This study was conducted for the various anthropogenic influence on exposed shores and the structural role of few dominant macrofauna on the shores, were demonstrated by field experiments. Extensive field study was regularly carried out along the entire coastal zone of Saurashtra region. The study sites were identified and make a note of the type of various anthropogenic activities such as tourism, fisheries, port activity, industry, sewage and disposal waste and later than classify it's to the degree of these activities which is actually more affected on the coastal area. For the prediction of likely nature and impact of anthropogenic stress, various environmental indicators were selected subject to the relevance to the study area. Further, direct, indirect, cumulative and unavoidable impacts were examined to assess the predictive impact. The coastal area is mainly polluted by the water pollution; it is directly or indirectly created by human and industrial settlement near the coastal area as well as natural procedure, which is tremendously affected the intertidal community. In the present study heavy metal analysis in sea water which affects the water quality were used for describe the coastal pollution and its effects on the intertidal macrofauna.

3.10. Data Analysis

According to Warwick and Clarke (1991), the available statistical methods for data analysis could be categorized broadly into different methods such as univariate, graphical/distributional and multivariate. This terminology is widely used for the study of benthic ecology.

3.10.1. Similarity Indices

The major groups responsible for the distribution of the species at different localities Sorensen's index of similarity (Sorensen, 1948) has been used to compare the similarity in species composition of the mollusca between sampling sites. It was calculated using following equation.

$$\mathbf{QS = 2C / A + B}$$

Where, A and B are the species numbers in samples A and B, respectively, and C is the number of species shared by the two samples.

3.10.2. Population Ecology

Among the ecological attributes, seasonal variations in the population density and abundance of major prominent molluscan species in each sampling stations were calculated (Misra, 1968). The collected data of ecological attributes were calculated by below formula were treated as raw data from which the total density, total abundance and total frequency values were calculated.

$$\text{Density} = \frac{\text{Total number of individuals recorded from the sample plot}}{\text{Total number of sample plot studied}}$$

$$\text{Abundance} = \frac{\text{Total number of individuals recorded}}{\text{Total number of sample plot where the individuals occurred}}$$

$$\text{Frequency (\%)} = \frac{\text{Number of sample plot where the species occurred} \times 100}{\text{Total number of sampled plot where the individual occurred}}$$

3.10.3. Statistical Analysis

The collected monthly data were presented as seasonally for the seasonal approach like winter, summer, monsoon and post-monsoon then calculated statistically like mean and standard deviation. The obtained data were subjected to different statistical analyses for their cumulative acceptability (Sokal and Rohlf, 1969). All the data was calculated automatically by using Microsoft Office Excel software. Significance of spatial and temporal variations was compared by using single factor ANOVA. Regression coefficients analysis was also performed to find out relationship between various metals in seawater and few prominent molluscan species within a sampling site, to assess the influence of trace metals on the few indicator species in the intertidal zone (Shouthwood, 1978).

Chapter - IV: Results

4.1. Coast characteristics

The Saurashtra coast along the Arabian Sea showed a typical characteristic. The intertidal belt is totally rocky formed of milliolite rocks except some interruption of sand patches where ever the so called spray zone is sandy. The rocky surface is very much sharp edged with abundant pools and puddles. Inter-faunal competition is quite high as available habitable spaces at the different zones are very less. The belt is mostly harbored by hard shelled molluscs and hermit crabs. Soft molluscs and crabs are less at certain areas.

The selected intertidal zone of Dwarka is on the north-east of the town. The available intertidal area is rocky with hard substratum having many big cup-holes and clavicles, whereas, the outer intertidal zone is highly elevated with broad and deep caves because of heavy wave action (Plate 2). The rocky surface is very much sharp edged with abundant pools and puddles. Selected sites are sandy, stony and calcareous eruptions. The intertidal belt of Mangrol is interspersed with many tide pools, puddles, crevices and small channels (Plate 3). The upper portion of the intertidal belt is generally covered with an admixture of silt and sand mixed with pieces of broken shells. The upper intertidal pools have light accumulation of sand settled over the rocky base. The intertidal zone is not very wide, generally dynamic wave action due to this reason.

The substratum of Veraval coast is mainly rocky with a few sandy patches (Plate 4). The lower littoral zone of Veraval ends up at steep vertical decline towards subtidal zone. The intertidal belt of this area is not uniform and exposure of this predominantly rocky shore is not significantly long. The intertidal zone covers a distance of about 60-90 m during spring tides. The available intertidal zone of Kodinar is hard flat rocky littoral area having small sized depressions in interspersed with many rocky pools and puddles (Plate 5). The intertidal belt is interrupted by many small tide pools. The upper littoral zone sharply ends up at spray zone. The middle and lower littoral zone share almost one and the same features from the point of view of types of substratum and prevailing biotic composition at all the sampling sites.

4.2. Intertidal Zonation

The intertidal portion of selected sampling locations at the Saurashtra coast was broadly divided in to four distinct zones such as spray zone, upper littoral, middle littoral and lower littoral zone, which does not show any significant slope while exposed during the lower tides. The spray zone is the driest area and never submerged and only receives ocean water due to the splash from crashing waves. The upper littoral zone is only submerged briefly during the highest tides. Few organisms can withstand the extreme fluctuations in moisture, temperature and salinity found in this zone. The gastropod *Cellana radiata* and *Turbo coronetus* are the most common forms in the upper littoral zone of the shore. The upper zone is dominated by green algae like *Ulva sp.* particularly. The middle and the lower littoral zones at most of the sampling sites harbored similar type of biota. The pools at the middle littoral zone were too deep. The bottom part of these pools was open to the sea, so regular thrust of upcoming tidal water. The middle littoral zone was dominated by a variety of algae and macrofaunal species. This is the portion which gets exposed during regular low tide. Most of the space of this zone was occupied by sessile organisms such as *Balanus amphitrite, Zoanthus sp.* and sea anemone. The barnacle was also dominated on the upper littoral and upper part of middle littoral zone and usually in patches. The lower littoral zone ended up with sharp decline to the sub tidal zone and that is too irregular. Some species of echinodermata were occurred in this zone such as *Strongylocentrorus sp.* and other gastropods like *Octopus vulgaris* was also found mainly at the lower littoral zone.

4.3. Intertidal Macrofaunal Diversity

The entire intertidal belt of the study area has been thoroughly surveyed to make a quantitative assessment of intertidal macrofauna. A total of 120 intertidal macrofaunal species belonging to seven diverse phyla were identified throughout the study period (Table 1). Among that 6 species of porifera, 17 species of coelenterata, 3 species of platyhelminthes, 8 species of annelida, 15 species of arthropoda, 65 species of mollusca and 6 species of echinodermata were observed for the duration of the entire assessment in selected intertidal belt at Saurashtra peninsula. Among all the recorded groups mollusca, coelenterata and arthropoda was most prominent groups for the major macrofaunal population of selected intertidal zone.

The selected sampling locations along the Saurashtra coastline off Arabian Sea are predominantly rocky with some patches of sand which is represented various macrofauna and flora species. The macrofaunal species number varied between 82 to 100 at Kodinar and Dwarka respectively. From the intertidal region at the Mangrol and Veraval sampling site, a total of 92 and 91 species of macrofauna were recorded. The result of macrofaunal diversity did not showed significant variations between sampling sites studied. Major components of the community were mollusca followed by coelenterata and arthropoda. Phylum porifera showed less number of species compare to the other phylum except platyhelminthes.

The phylum porifera comprised six species along the selected locations of the study area. Among them *Grantia sp.* and *Leucosolenia punctata* were recorded at Mangrol and Dwarka respectively, while *Helichondria panacea* and *Oscareila lobularis* were found at all the sampling sites throughout the study period. The sponge was mostly found at the lower littoral zone under the rocks. Its population was relatively less during the study, while it was comparatively high at Dwarka than the other sampling sites. The species occurrence were showed almost similar pattern at all the sampling sites throughout the study period.

In the phylum coelenterata, a total of 17 species were recorded during entire study period. There were 6 species of corals and another 11 species of other than corals observed in the littoral zone of the selected intertidal area. Among the coral *Goniastraea pectinata, Hydnophora exesa* and *Montipora folisa* were recorded at all the sampling sites. Whereas, *Favia favulus* and *Goniopora sp.* were found at Dwarka and Mangrol respectively. Corals were mostly found at middle and lower littoral zone of the intertidal belt throughout the study sites. In case of other than corals most of the species were recorded at middle littoral zone, while *Zoanthus sociatus* and *Protopalythoa vestitus* were also found at upper littoral zone during the study. Besides *Zoanthus sociatus, Anthopleura sp., Metridium sp.,Palythoa tuberculosa, Physalia physalia* and *Porpita porpita* were also recorded from the intertidal belt of the selected sampling sites. *Metridium sp.* was observed at middle littoral zone and further more in upper part of lower littoral zone at each sampling locations. Other coelenterate like *Isaurus tuberculata* and *Utricina sp.* were observe at Mangrol and Veraval during the study time.

There was three species recorded in phylum platyhelminthes. *Pseudoceros susanae* was found at all the sampling locations throughout the study time. *Pseudoceros indicus* and *Pseudoceros stellae* were observed at Dwarka and Veraval during post-monsoon and winter seasons respectively. The animals recorded in this phylum were mainly attached with algae and preferred mostly specific part of intertidal region such as pools.

The phylum annelida have been comprised eight species along the study area, among that all the species were recorded at Dwarka throughout the study period. *Nereis pelagic* and *Hetronereis sp.* were commonly found in middle and lower littoral zone during the study and mostly occurred in the sandy portion of the intertidal area. *Chetopterus chetopterus, Eulalia viridis* and *Sabella pavonica* were also observed at all the sampling sites. The annelids were mainly seen in middle and lower littoral zone and rarely showed in upper littoral zone during the study. *Serpula vermicularis* was recorded in the middle and lower littoral zone during study time at the sampling site Dwarka. *Baseodicus hemprichii* was recorded maximum time at Dwarka and Mangrol mostly in middle littoral zone. Animals of phylum annelida were observed in each littoral zone of the intertidal area.

At all the sampling sites 15 species of arthropods were recorded during the study. The species diversity showed more or less similar pattern at upper and middle littoral zones and least species diversity observed at lower littoral zone. *Clibanarius zebra* and *Clibanarius nathi* were recorded in the entire littoral zone at the study area and present in deserted shell of gastropod molluscs. *Atergatis sanguinolentus, Balanus Amphitrite* and *Carcinus means* was prominent species at all the sampling sites and recorded commonly at the entire littoral zone of all the sampling sites throughout the study. *Pinaeus indicus* and *Pinaeus Monodon* were observed at almost all the sampling sites of the selected coast. Phylum arthropoda was more diverse in Dwarka and Mangrol sampling site, however *Portunus pelagicius* and *Squilla squilla* were observed only at Mangrol during study period. Crabs were recorded in each littoral zone followed by spray zone at all the sampling sites.

Mollusca were most prominent phylum than any other phylum in the selected intertidal belt of the Saurashtra coast. About 65 species of mollusca were recorded during the entire study period in the intertidal belt of selected locations. Among all the molluscan species, Some common species like *Nerita albicilla, Chiton peregrinus, Cellana radiata, Mancinella bufo, Cerithium caeruleum, Conus miliaris, Turbo intercostalis, Turbo coronetus* and *Trochus radiatus* were found mostly in littoral zone, while in middle littoral zone all species were present except some molluscan species without shell like *Aplysia oculifera, Berthellina citrina* and *Octopus vulgaris* which were present in middle and lower littoral zone. Phylum mollusca were mostly seen in upper and middle littoral zone compare to the lower littoral zone. Animals of this group are mainly feed on the marine algae and thus always associate with intertidal sea weeds. *Astrea semicostata* is the species that competes with the *Trochus radiatus* at all the sampling sites. The vertical upper littoral zone is uniformly covered by small sized *Cellana radiata* and *chiton peregrinus* and *Turbo coronetus,* whereas *Siphoneria siphoneria* was also observed in the upper littoral zone throughout the study. *Clavus clasa, Nerita chamaeleon, Pyrene marquessa* and *Cerithium morus* were observed only at sampling site Veraval, while *Dosinia cretacea* and *Xancus pyrum* were recorded at Mangrol throughout the study period. *Hexaplex cichoreus, Janthina globosa* and *Clavus clasa* were recorded at few sampling sites throughout the study period. The selected intertidal belt of Saurashtra coast is mainly rocky-sandy. The middle littoral zone consist mainly rocky substratum with broad variety of algal population than the upper littoral zone, it provides ideal habitat for the most of molluscan species. Higher population of *Onchidium verruculatum* was found in Veraval and Mangrol during most of the seasons. During the winter season the population was quite high than the post monsoon at almost all the selected sites.

In case of phylum echinodermata a total of six species were found at entire study area. Among that *Ophioderma brevispinum* was present at all the sampling sites. The members of this phylum were totally absent in upper littoral zone but abundantly occurred in middle and lower littoral zone. All six species were recorded at Dwarka, while three species at Mangrol and Veraval. The species diversity of this phylum was comparatively less at all the selected intertidal region of the study area. Most of the species of this phylum were recorded during post-monsoon and winter season at the selected sampling sites. The higher numbers of species in this phylum were observed at Dwarka than the other sampling sites.

Table 1. Checklist of the intertidal macrofauna recorded at various sampling sites along the Saurashtra coast during the study period (+ or – signs denote presence or absence of species).

Phylum: Porifera

No.	Name of species	Dwarka	Mangrol	Veraval	Kodinar
1.	*Grantia sp.*	-	+	-	-
2.	*Halichondria panicea*	+	+	+	+
3.	*Leucosolenia punctata*	+	-	-	-
4.	*Microciona sp.*	+	+	+	+
5.	*Oscareila lobularis*	+	+	+	+
6.	*Tethya sp.*	+	+	+	+

Phylum: Coelenterata

No.	Name of species	Dwarka	Mangrol	Veraval	Kodinar
	Corals				
1.	*Favia favulus*	+	-	-	-
2.	*Goniastraea pectinata*	+	+	+	+
3.	*Goniopora sp.*	-	+	-	-
4.	*Hydnophora exesa*	+	+	+	+
5.	*Montipora folisa*	+	+	+	+
6.	*Portis lutea*	+	+	+	-
	Other than Corals				
7.	*Anthopleura sp.*	+	+	+	+
8.	*Auralia aurita*	+	-	+	-
9.	*Isaurus tuberculata*	-	+	+	-
10.	*Metridium sp.*	+	+	+	+
11.	*Palythoa tuberculosa*	+	+	+	+
12.	*Physalia physalia*	+	+	+	+
13.	*Porpita porpita*	+	+	+	+
14.	*Protopalythoa vestitus*	+	+	+	+
15.	*Utricina sp.*	-	+	+	-
16.	*Vellella vellella*	+	-	-	-
17.	*Zoanthus sociatus*	+	+	+	+

Phylum: Platyhelminthes

No.	Name of species	Dwarka	Mangrol	Veraval	Kodinar
1.	*Pseudoceros indicus*	+	-	-	-
2.	*Pseudobiceros stellae*	+	-	+	-
3.	*Pseudoceros susanae*	+	+	+	+

Phylum: Annelida

No.	Name of species	Dwarka	Mangrol	Veraval	Kodinar
1.	*Baseodicus hemprichii*	+	+	+	+
2.	*Chetopterus chetopterus*	+	+	+	+
3.	*Eulalia viridis*	+	+	+	+
4.	*Eurythoa complanata*	+	+	-	-
5.	*Hetronereis*	+	+	+	+
6.	*Nereis pelagica*	+	+	+	+
7.	*Sabella pavonica*	+	+	+	+
8.	*Serpula vermicularis*	+	-	-	-

Phylum: Arthropoda

No.	Name of species	Dwarka	Mangrol	Veraval	Kodinar
1.	*Atergatis sanguinolentus*	+	+	+	+
2.	*Balanus amphitrite*	+	+	+	+
3.	*Cancer pagurus*	+	-	+	+
4.	*Carcinus means*	+	+	+	+
5.	*Clibanarius zebra*	+	+	+	+
6.	*Clibanarius nathi*	+	+	+	+
7.	*Pachygrapsus crassipes*	+	+	+	+
8.	*Pagurus longicarpus*	+	+	+	+
9.	*Palaemon serratus*	+	+	+	+
10.	*Pilumnus hirtellus*	+	+	+	+
11.	*Pinaeus indicus*	+	-	+	+
12.	*Pinaeus monodon*	+	+	+	-
13.	*Portunus granulatus*	+	-	-	+
14.	*portunus pelagicius*	-	+	-	+
15.	*Squilla squilla*	-	+	-	-

Phylum: Mollusca

No.	Name of Mollusca	Dwarka	Mangrol	Veraval	Kodinar
1.	*Aplysia oculifera*	+	+	+	+
2.	*Architectonica laevigata*	-	+	+	-
3.	*Austrea stellata*	+	+	+	+
4.	*Babylonia spirata*	+	-	+	-
5.	*Beguina variegata*	+	+	-	-
6.	*Berthellina citrina*	+	-	-	-
7.	*Brusa granularis*	+	+	+	+
8.	*Cantharus spirallis*	+	+	+	+
9.	*Cantharus undosus*	+	+	+	+
10.	*Cellana radiata*	+	+	+	+
11.	*Cerithium caeruleum*	+	+	+	+
12.	*Cerithium columna*	+	+	+	+
13.	*Cerethium morus*	-	-	+	-
14.	*Cerithium scabridum*	+	+	+	+
15.	*Chiton peregrinus*	+	+	+	+
16.	*Clavus clasa*	-	-	+	-
17.	*Conus miliaris*	+	+	+	+
18.	*Conus cumnigii*	+	-	+	+
19.	*Conus figulinus*	+	+	+	+
20.	*Cronia crontracta*	+	+	+	-
21.	*Cronia subnodulosa*	+	+	+	+
22.	*Cypraea isabella*	+	+	+	+
23.	*Cyprea lynx*	+	+	+	+
24.	*Cyprea ocellata*	-	+	-	+
25.	*Dosinia cretacea*	-	+	-	-
26.	*Engina zea*	+	+	+	+
27.	*Euchelus asper*	+	+	+	+
28.	*Hexaplex cichoreus*	-	+	-	-
29.	*Janthina globosa*	+	-	-	+
30.	*Mancinella bufo*	+	+	+	+
31.	*Mitra ambigua*	+	+	+	+
32.	*Mitra scutulata*	+	+	+	+
33.	*Monodonta australis*	+	+	+	+
34.	*Murex bruneus*	+	+	+	+
35.	*Murex ternispina*	+	+	+	+
36.	*Mytilus sp.*	+	-	-	-

Table Continue……

37.	*Nassarius canaliculata*	+	-	+	-
38.	*Nassarius distortus*	+	+	+	-
39.	*Nassarius olivacea*	-	+	-	+
40.	*Nerita albicilla*	+	+	+	+
41.	*Nerita chamaeleon*	-	-	+	-
42.	*Octopus vulgaris*	+	+	+	+
43.	*Oliva globosa*	-	+	+	-
44.	*Oliva oliva*	+	+	+	+
45.	*Onchidium verruculatum*	+	+	+	+
46.	*Paphia ala-papilionis*	+	-	-	+
47.	*Perpura panama*	+	+	+	+
48.	*Pyrene flava*	-	-	+	+
49.	*Pyrene marquessa*	-	-	+	-
50.	*Pyrene terpsichore*	+	+	+	+
51.	*Rhinoclavis sinensis*	+	+	+	+
52.	*Siphoneria Siphoneria*	+	+	+	+
53.	*Sunetta donacia*	+	+	+	+
54.	*Telescopium telescopium*	-	-	-	+
55.	*Thais lacera*	+	-	-	-
56.	*Thais rugosa*	+	+	+	+
57.	*Tibia insuladchorab*	+	+	+	+
58.	*Trachicardium flavum*	+	+	-	-
59.	*Trochus radiatus*	+	+	+	+
60.	*Turbo brunnes*	-	+	-	-
61.	*Turbo cornetus*	+	+	+	+
62.	*Turbo intercostalis*	+	+	+	+
63.	*Venerupis microphylla*	+	-	-	+
64.	*Venus reticulate*	+	+	+	+
65.	*Xancus pyrum*	-	+	-	-

Phylum: Echinodermata

No.	Name of species	Dwarka	Mangrol	Veraval	Kodinar
1.	*Antedon sp.*	+	-	+	+
2.	*Asterina gibbosa*	+	-	-	-
3.	*Clymeaster sp.*	+	+	-	-
4.	*Echinus sp.*	+	-	+	-
5.	*Ophioderma brevispinum*	+	+	+	+
6.	*Strongylocentrorus sp.*	+	+	-	-

4.4. Algal Diversity

The results revealed that the intertidal area of the selected sampling sites of the Saurashtra coast were rich in algal population. The spatial distribution of marine algae in the selected area is depicted in table 2. As many as 51 intertidal seaweed (algae) species recorded during the study period at all the sampling locations along the Saurashtra coast. As a whole, 18 species belonging to class Chlorophycea and Pheophyceae followed by 15 species of algae belonging to class Rhodophyceae were found in the selected intertidal region all over the study time.

It was found from the present study the upper littoral zone is mostly covered with green algae (class Chlorophycea). The algal species belonging to class Chlorophycea like, *Ulva lactuca, Ulva fasciata, Caulerpa racemosa, Caulerpa scalpelliformis* were prominent at the intertidal region of all the selected sites. Large mashes of *Ulva lactuca* and other species like *Caulerpa racemosa* was found in each littoral zone at almost all the sampling locations. As far as the seasonal variation is concerned it is negligible during monsoon season, whereas optimum growth of algae had been observed during the post-monsoon season. It was also found that high species diversity of chlorophycea recorded at the sampling site Dwarka, which represented 17 species, while in case of Kodinar sampling site, there were found only 11 species during the study period. Similarly, it was also found in case of class Pheophyceae and Rhodophyceae.

Caulerpa scalpelliformis, Halimeda tuna, Padina gymnospora, Turbinaria ornata, Gracilaria corticata and *Laurencia papillosa* was the highly abundant species in to all the selected sampling sites. *Sargassum johnstonii* and *Sargassum swartzii* had the widest distribution, being able to colonize in lower littoral zone at all sampling sites along the Saurashtra coast. In contrast, some species were found only at specific sites, for example, *Hydroclathrus clathratus* and *Halymenia porfaroides* occurred only at Dwarka, while *Dityota atomaria* occurred only at Mangrol and *Halimeda macroloba* was found at Mangrol and Veraval throughout the study. Algal species of class Phaeophycea and Rhodophycea were generally recorded in middle and lower littoral zone, while in some extent it was found negligible in upper littoral zone at the study sites.

Table 2. Checklist of the intertidal algae recorded at various sampling sites.

Class: Chlorophycea

No.	Name of species	Dwarka	Mangrol	Veraval	Kodinar
1.	*Enteromorpha sp.*	+	+	+	+
2.	*Ulva fasciata*	+	+	+	+
3.	*Ulva lactuca*	+	+	+	+
4.	*Chaetomorpha antennina*	+	+	+	+
5.	*Cladophora glomerata*	+	-	+	-
6.	*Valonia aegagroplia*	+	+	-	-
7.	*Bryopsis plumose*	+	+	+	+
8.	*Caulerpa racemosa*	+	+	+	+
9.	*Caulerpa scalpelliformis*	+	+	+	+
10.	*Caulerpa taxifolia*	+	+	+	+
11.	*Codium dwarkense*	+	+	+	+
12.	*Halimeda tuna*	+	+	+	+
13.	*Halimeda cylindracea*	+	+	+	-
14.	*Halimeda cuneata*	+	+	-	-
15.	*Halimeda macroloba*	-	+	+	-
16.	*Udotea patiolata*	+	+	-	-
17.	*Boergesenia forbesii*	+	+	+	+
18.	*Galidiopsis intricata*	+	+	-	-

Class: Phaeophycea

No.	Name of species	Dwarka	Mangrol	Veraval	Kodinar
1.	*Dictyota dichotoma*	+	+	+	+
2.	*Dityota atomaria*	-	+	-	-
3.	*Padina gymnospora*	+	+	+	+
4.	*Padina tetrastromatica*	+	-	+	+
5.	*Colpomenia sinuosa*	+	+	+	+
6.	*Cystoseria indica*	+	+	+	+
8.	*Sargassum johnstonii*	+	+	+	+
9.	*Sargassum swartzii*	+	+	+	+
11.	*Sargassum cinereum*	+	-	+	-
12.	*Turbinaria ornata*	+	+	-	-
13.	*Stoechospermum marginatum*	+	+	+	+
14.	*Spatoglossum asperum*	+	+	+	+
15.	*Colpomenia tuberculata*	+	+	+	+
16.	*Colpomenia sciniosa*	+	+	-	-
17.	*Etcocarpus sp.*	+	+	-	+
18.	*Hydroclathrus clathratus*	+	-	-	-

Class: Rhodophycea

No.	Name of species	Dwarka	Mangrol	Veraval	Kodinar
1.	*Gracilaria corticata*	+	+	+	+
2.	*Ceramium truncatum*	+	-	+	-
3.	*Amphiroa anceps*	+	+	+	+
4.	*Grateloupia indica*	+	+	+	-
5.	*Champia compressa*	+	+	+	+
6.	*Champia indica*	+	+	+	+
8.	*Gelidiella acerosa*	+	+	+	+
9.	*Halymenia venusta*	+	+	-	-
11.	*Halymenia porfaroides*	+	-	-	-
12.	*Polysiphonia sp.*	+	+	+	+
13.	*Subdenia sp. (flabellata)*	+	+	-	-
14.	*Laurencia papillosa*	+	+	+	+
15.	*Galaxaura oblongata*	+	+	+	+

4.5. Species Composition of Intertidal Mollusca

A total of 65 species of molluscan group consisting of 55 species belonging to class gastropods, 8 species in class bivalvia, and the rest of class amphineura and cephalopoda, which were represented one species each, identified during the field survey. The number of species occurring at each region was 51species in Dwarka, 50 species in Mangrol and Veraval and 45 species in Kodinar (Figure 1). Among the molluscan individuals, some were very prominent and used to show very prominent dominance at different locations.

The gastropods are the largest and most diverse class of molluscs, comprising more than half of all molluscan species. They include the snails and slugs, limpets, cowries and cones. Most of these animals have a single coiled shell but in some the shell is limpet-like, rudimentary. The bivalves are laterally compressed, typically bilaterally symmetrical molluscs with a shell composed of two hinged valves. They are an economically important group including the oysters, mussels and clams. All the bivalves are major sources of food for humans. The Cephalopoda are a group of highly organised, exclusively marine molluscs that include the familiar squids and octopus. Amphineura, the C*hitons* have a flattened body and a broad foot, and a shell of (usually) eight articulated calcareous plates or valves. These plates allow the animal to either fasten itself tightly to an irregular surface. *Chitons* are usually found attached to hard surfaces such as rocks or seaweed blades, particularly in intertidal coastal waters, although some groups are found in deeper waters. Most *Chitons* are generalist grazers (herbivores and omnivores), feeding on algae or small encrusting animals.

Among the gastropods, *Mancinella bufo, Cantharus spirallis, Conus miliaris, Cellana radiate, Astrea stellata, Monodonta australis, Trochus radiatus, Turbo coronetus, Turbo intercostalis, Cerithium caeruleum, Rhinoclavis sinensis and Aplysia oculifera* were dominant at all the sampling sites during each season. In general maximum number of gastropods, at all the sites was observed during post-monsoon and winter seasons. Eight species of bivalves were recorded, namely, *Dosinia cretacea, Paphia ala-papilionis, Sunneta donacia, Venerupis microphylla, Venus reticulate* belonging to family veneridae and *Mytilus sp., Trachicardium flavum* and *Beguina variegate* belonging to family mytilidae and cerdiidae respectively. A relatively high number of species were recorded on the Dwarka coast (Figure 1). Generally, species composition was similar across the sites, with consistently dominating the gastropod fauna and the rest other two class like amphineura and cephalopoda which was represented species such as *Chiton peregrines* (family: chitinidae) and *Octopus vulgaris* (family: Octopadidae) respectively. In case of bivalvia species like *Beguina variegate*, family carditidae was commonly distributed along the sampling site Dwarka and Mangrol, while it was totally absent at Veraval and Kodinar throughout the study period.

The overall results showed that the gastropods were highly occurred on the intertidal belt of the Saurashtra coastal region. Distribution of the mollusca at varies sites mainly due to the pattern of the intertidal substratum offered to them. In fact, in each sampling locations, the substratum condition and exposure area were different than each other. Thus, the space available for movement and shelter differs markedly with the change of the location. The other most important factor that regulates the distribution is the physical parameters that are external to the system from the biological point of view. One such factor is the tidal force which varies so significantly with the locations that this has become one of the key controlling factors for the spatial distribution of intertidal mollusca. The middle littoral zone of the sampling site was a place apparently suitable for so many species as there was virtually no difference between the middle and the lower zone.

The results did not show high variation in the species composition of mollusca among the different sites along the Saurashtra coastline. The Sorenson's index of similarity allowed to compares the species composition between different sampling sites. The similarity index of four sites indicates that Dwarka and Kodinar sites are more similar throughout the study period followed by Mangrol and Veraval (0.840) and Veraval and Kodinar (0.833). The lowest value of similarity found between Mangrol and Kodinar (0.812), while between other sampling sites the results did not showed much fluctuation throughout the study period (Table 3).

Table 3. Sorenson's index of similarity for occurrence of intertidal molluscan species at four sampling sites.

	Dwarka	Mangrol	Veraval	Kodinar
Dwarka	1.000			
Mangrol	0.832	1.000		
Veraval	0.832	0.840	1.000	
Kodinar	0.866	0.812	0.833	1.000

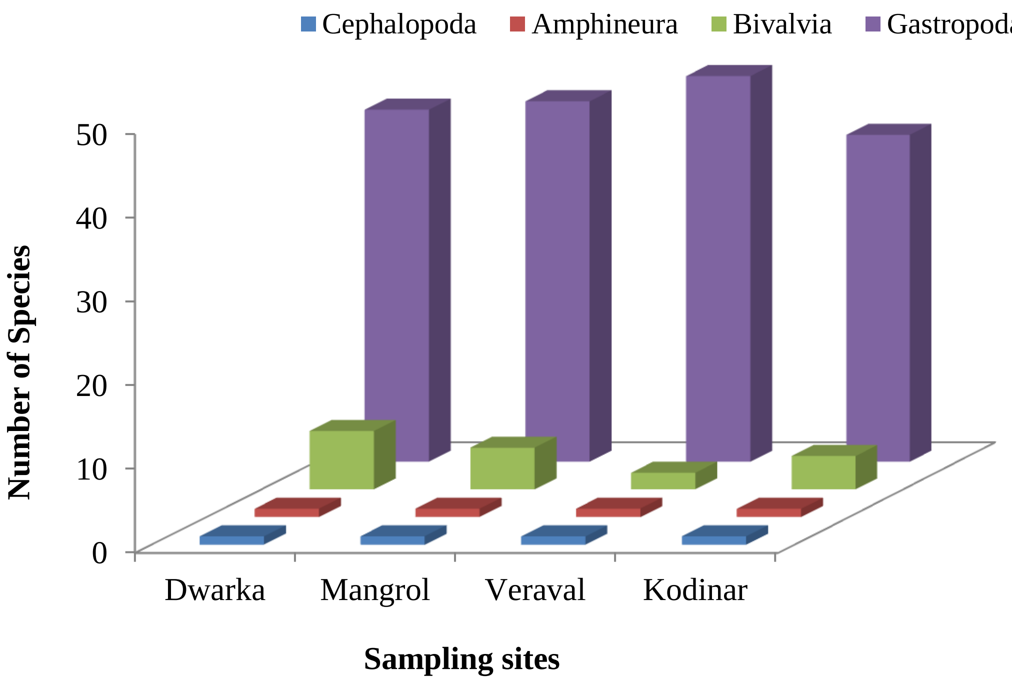

Figure 1. Number of species found in various class of phylum Mollusca at four different sampling sites during the study period.

4.6. Introducing the Species Studied for Population Ecology

In the present study all the four selected sampling sites off the Saurashtra coast were frequently surveyed at regular interval during the lowest tide at day time. It was apparent from the baseline study of intertidal macrofauna that phylum mollusca were dominated along the selected intertidal belt of the Saurashtra coast. Among the molluscan group gastropods were most abundant and found at the entire littoral zone throughout the study. For the population ecological studies seven species of gastropods belonging to molluscan group were selected. During the study, it was found that seven species, viz. *Mancinella bufo, Conus miliaris, Trochus radiatus, Turbo coronatus, Turbo intercostalis, Nerita albicilla* and *Rhinoclavis sinensis* were dominate at all the coastlines studied. Thus, for the ecological studies, faunal attributes like frequency, abundance and density of these dominant molluscan species were measured.

4.6.1. *Mancinella bufo*

- The maximum shell length is about 70 - 80 mm. The shell is variably shaped, generally with a raised spire and strong sculpture with spiral ridges and often axial varices frequently bearing spines, tubercles or blade-like processes. Shell broad, conical in shape, strongly raised spot on the shell surface, foot opening is wider, thus needs sufficient opening to settle.
- It is found on littoral rocks in sandy pools, and in estuaries. The species is most common in tropical and subtropical shallow waters. This species is known as active predators which generally feeding on other molluscs and barnacles.
- Stable in distribution. But pressure from the local people and fisherman affect its distribution. It is commonly collected for their edible flesh or for their beautiful shell which is used for shell craft.

4.6.2. *Conus miliaris*

- The shell Length is about 40-50 mm. cone-shaped shell, conical to flat spire and a well-developed body whorl tapering towards the narrow anterior end. Sculpture variable but generally reduced, sometimes tuberculate on shoulder. Fleshy siphon of the mantle well developed. The colour of shell is straw yellow brown with prominent spiral white band across the middle body whorl.

- Most common in intertidal and shallow sublittoral zones, but also occurring deeper on the continental shelf and slope to a depth of about 400 m. Mostly reef-dwellers, living in clean or muddy-sand bottoms under rocks. Active predators, armed with sharp arrow like teeth and a poisonous gland which secretes a powerful nerve toxin.
- These animals are found on the west coast extending from Okha. They are known to be locally used as food and shell craft.

4.6.3. *Trochus radiatus*

- The average shell length of this species is about 30-40 mm. They are moderately large, heavy and conical in shape and longer than wide, with pointed apex. Slow moving animals, browsing on detritus and algae. Outside colour of the shell is yellowish or pinkish white with deep red axial flammules. Beached surf-washed specimens usually bleached.
- Mostly occurring in littoral and shallow sublittoral and mainly occurring in large numbers on hard substrates like rocky shores or coral reefs usually near low tide mark. It is comparatively less sensitive to seasonal changes.
- Most common species *Trochus* are traditionally used as food by coastal populations and Shells are utilized by the shell craft industries.

4.6.4. *Turbo coronetus*

- The maximum shell length 30-35 mm. This turbinid is equipped with a very hard, thick shell. Foot opening is very small, thus can attach itself within a very small area. Spires low with large body whorl. Surface bears blunt spines. Light brown colour with white mottling.
- Rock dweller, but reported to be found in the clayey surface. Mainly living in shallow waters of warm temperate and tropical seas, especially on rocky and coral reef habitats. Mostly found among rocks and gravel, or in crevices of Intertidal area. Prefer semi exposed condition. Found on the upper and upper middle littoral zones. Usually found in cluster. Prefer pools and walls of the crevices where water accumulates for a longer duration.
- Commonly occurred and reported from the entire Saurashtra coast. Animal is comparatively less sensitive to seasonal changes because of that quite firm distribution along the study sites. Collected locally for food and shell craft.

4.6.5. *Turbo intercostalis*

- *Turbo intercostalis* found mostly in large Shell, the maximum shell length 50-60 mm. The shell is solid and heavy, length about equal to or slightly greater than width. Spire well developed, pointed, Outside of shell either whitish or irregularly marbled with green and brown, or uniformly greenish.
- Found in all the three intertidal zones, mainly in middle and lower littoral zones. Moreover, Coral reef areas, in moderately exposed habitats and in lagoons of atolls.
- Edible species, used as food usually eaten by local fisherman, but also the shell locally serves also for craft industry and making buttons.

4.6.6. *Nerita albicella*

- The shell length is about 30-35 mm. Thick shell, globose, with a flat spire, width conspicuously greater than length. Outer surface dull, with broad and low, rounded spiral cords. The outer coloration is very variable, mostly white or cream, and often spirally banded with grey, brown, black, or orange
- Along shorelines in warm temperate to tropical, marine, brackish, or even fresh-water habitats. The Species is abundant in rocky shores, forming dense colonies in upper-mid tidal pools, on damp and submerged rocks and in crevices. Herbivorous animals, which is prefer grazing during night at low tide on fine algae and detritus covering the bottoms where they live.
- This species is ecologically better positioned along the entire Indian Ocean. This animals is Collected for its edible flesh and for its shell in various purpose.

4.6.7. *Rhinoclavis sinensis*

- Maximum shell length is about 40-45 mm. The shell is thick, narrow, conical shape, strongly raised spiral spotted ridges on the shell, surface foot opening is narrow, thus, can attach itself within a very small area. Prefer pools and walls of the crevices where water accumulates for a longer duration. Fertilization is external.
- An important species off the Coromandel coast of India. Commonly found in Intertidal and sublittoral, region especially on the middle littoral zones. It is frequently heavily preyed upon by other gastropods or by crabs.
- The species is reported from the entire Saurashtra coast. Collected for food and also used in craft industries.

4.7. Population Ecological study

4.7.1. *Mancinella bufo*

Population density

Mancinella bufo was dominant species found to be at all the sampling sites. It is a solitary animal and rarely found in groups. It is the member of Family Muricidae. Population density of *Mancinella bufo* showed irregular pattern among the season as well as site wise. Density value was recorded high during winter and post-monsoon seasons at all the sampling sites. The highest density values were recorded in middle littoral zone compare to upper and lower littoral zone at all the study locations throughout the study period (Figure 9 to12). Maximum density value was recorded at Veraval (0.57 no/0.25m^2) in winter season and at Mangrol (0.53 no/0.25m^2) in post-monsoon season than those of the other sites. Density values were ranging from 0.27 no/0.25m^2 at Kodinar site and 0.44 no/0.25m^2 at Mangrol sampling site. Ecological attributes showed a gradual decline values in population density from post-monsoon to summer, but showed an incline thereafter in monsoon season at all the selected location, while in case of Veraval, population density value was recorded maximum during winter seasons (Figure 2a).

Population abundance

From the present study, a result of the population abundance values suggests the species to be a colonial one on the intertidal belt. This may be the cause for the comparative higher abundance value than the density. Like density, the abundance values were also found to be higher at Mangrol (Figure 2b). Abundance values did not show any clear trend in zonal distribution. This species was abundantly found in all the littoral zones but in case of Veraval abundance values showed higher in middle littoral zone throughout the seasonal distribution (Figure 11). At all the sampling sites, highest values were observed during post-monsoon at Mangrol (1.17 no/0.25m^2), whereas lowest was observed during Monsoon seasons at Kodinar (1.00 no/0.25m^2) (Figure 2b). There did not observe significant difference in the population abundance value of *Mancinella bufo* during the study. However, similar fluctuations were throughout seasons. It was observed that the abundance values were found to be low during summer seasons (Figure 2b).

Population frequency

In the present study, the population frequency values also recorded higher at Mangrol than the other sites. The trend of frequency values was uniform with population density values at all four selected sampling sites. Maximum and minimum values counted (37.78 no/0.25m^2) at Mangrol and (25.56 no/0.25m^2) at Kodinar were during post-monsoon and summer respectively. Zonal distribution of frequency was same to the density. No significance difference in either site wise or season wise was evident from Table 5.

4.7.2. *Conus miliaris*

Population density

The animal showed nearly uniform distribution at all the study sites throughout the study period. This species have attractive colours and shapes. The population density values were ranged between narrow scales. The values range from 0.26 no/0.25m^2 to 0.39 no/0.25m^2 at Dwarka, 0.33 no/0.25m^2 to 0.47 no/0.25m^2 at Mangrol, 0.26 no/0.25m^2 to 0.42 no/0.25m^2 at Veraval and 0.29 no/0.25m^2 to 0.40 no/0.25m^2 at Kodinar during study period. There did not show any clear seasonal fluctuations in population density values. In case of zonal distribution, did not found any significant difference among all the sampling locations (Table 6 to 8). However, the density values showed higher in middle and lower littoral zone and minimum at upper littoral zone (Figure 13 to 16). The density values were found to be lower during summer season but the highest value at all the sites did not maintain a same timing.

Population abundance

This species was more abundant in lower littoral zone. Abundance values found to be very low at Veraval during all the seasons. The highest abundance values were recorded at Dwarka. The irregular pattern was observed in a seasonal value as well as within different sampling sites. Abundance values were ranged from 1.00 no/0.25m^2 to 1.22 no/0.25m^2 during summer and post-monsoon season at Kodinar and Dwarka respectively (Figure 3b). However, there was no significant difference in either between seasons or between sampling sites were observed (Table 5).

Population frequency

Frequency values observed higher in middle littoral zone while lower in upper littoral zone. The values were found to be higher during post-monsoon thereafter decreased to winter and incline trend was observed during monsoon season at Mangrol and Kodinar (Figure 3c). In case of Dwarka and Veraval moderate values were observed during post-monsoon, thereafter increased during winter season then decreased during summer and again increased during monsoon season throughout the study period (Figure 3c). Frequency values found higher at Mangrol in all four seasons, this trend was also observed in density values. There was no significant difference either in the population density or abundance values while compare between seasons as well as between sampling sites (Table 5).

4.7.3. *Trochus radiatus*

Population density

It is the only species that maintained a uniformity of higher values at Kodinar during all the seasons for all parameters studied. The clear cut spatial variations in density values illustrated from Figure 4a. The values recorded higher at Kodinar, and quite low at Mangrol and Veraval, and lesser values were noticed at Dwarka during all the seasons. At all the study sites population followed uniform fluctuation with the change of season. The zonal pattern showed regular trend at sampling sites, higher values were observed in middle littoral zone, but in case of upper and lower littoral zone moderate values were observed, while at Kodinar site less values were observed in lower littoral zone than the upper littoral zone (Figure 20). The density value were decreased during post-monsoon to summer and then after increased during monsoon season. Density values in this case, ranged from 0.30 no/0.25m^2 to 0.81 no/0.25m^2 during summer and post-monsoon season at Dwarka and Kodinar sampling sites respectively.

Population abundance

Abundance values showed narrow fluctuation within the spatial as well as seasonal distribution. The population abundance value remained higher at Kodinar during post-monsoon and winter season but during summer and monsoon season values remained higher at Mangrol. Zonal distribution of abundance values showed irregular pattern in all the sites during various seasons (Figure 17 to 20). The highest population values were recorded at Kodinar (1.61 no/0.25m^2) in middle littoral zone, same trend was observed in case of Dwarka and Veraval but in case of Mangrol the maximum abundance value was observed in upper littoral zone. The values ranged from 1.06 no/0.25m^2 to 1.44 no/0.25m^2 during winter to post-monsoon season respectively (Figure 4b). However, there was no significant spatial difference occur (Table 5).

Population frequency

From the present study it was observed that the frequency values of *Trochus radiatus* at all the sampling sites did not fluctuated during seasons. However, it showed increasing trend during winter season at Kodinar. The trend was little bit different at Dwarka, Mangrol and Veraval, where incline trend was observed during winter to monsoon season. Significant difference was showed in site wise distribution (Table 5). The frequency values found to be very high during all the seasons at the study area. Frequency values of Kodinar showed more fluctuation in zonal distribution. At all study sites, the frequency values remained highest in middle littoral zone during all four seasons (Figure 17 to 20).

4.7.4. *Turbo coronetus*

Population density

The density values at all the sites were varied quite narrowly with the change of seasons. The population density value showed a similar pattern of distribution for this snail at all the sampling sites (Figure 5a). The maximum density values were observed in upper littoral zone, moderate values observed at middle littoral zone and least values were observed in lower littoral zone during all the seasons at all the study sites . Density values of this molluscs showed higher value at Veraval during post-monsoon, winter and summer seasons but in monsoon season the observed value was high at Mangrol than other sites (Figure 5a). The values were calculated as 0.62 no/0.25m^2 to 0.72 no/0.25m^2, 0.57 no/0.25m^2 to 0.66 no/0.25m^2, 0.46 no/0.25m^2 to 0.54 no/0.25m^2 and 0.58 no/0.25m^2 to 0.66 no/0.25m^2 in range during post-monsoon, winter, summer and monsoon seasons respectively. But the minimum density values were observed at Kodinar during summer seasons.

Population abundance

This animal usually occurred in clusters, therefore the abundance values were found to be high. The abundance values showed fluctuation in seasonal data. However, there was no significant difference between sampling sites were observed. The abundance values recorded maximum in upper littoral zone but in some cases maximum values were observed in middle littoral zone (Figure 21 to 24). In post-monsoon season, maximum values were observed at Mangrol but in winter and summer season high value were observed at Veraval and in monsoon season high values was recorded at Dwarka. From the present study, it was evident that the abundance did not follow a definite trend at all the sites. The maximum abundance values were recorded 1.35 no/0.25m^2 at Dwarka, 1.41 no/0.25m^2 at Mangrol, 1.38 no/0.25m^2 at Veraval and 1.34 no/0.25m^2 at Kodinar.

Population frequency

From this study, it was observed that the frequency values at Mangrol fluctuate much during seasons and high value was noticed in monsoon season but in case of other sampling sites high values were observed during winter seasons. The frequency values found to be higher in upper littoral zone and least in lower littoral zone (Figure 21 to 24). The values were quite similar during winter but the difference reached its zenith during monsoon at all the sites. The values were more at Mangrol than other site though density values were recorded higher at Veraval sampling site. No significant difference in site wise was evident from Table 5.

4.7.5. *Turbo intercostalis*

Population density

This gastropod species showed comparatively lesser of population density than *Turbo coronetus*. Density values showed quite change with season. But the interesting point was that the species distributed equally in each of the study sites. However, the slight high values were observed at Mangrol during post-monsoon and winter. In density values decreasing trend was observed during post-monsoon to summer then the values slightly increased during monsoon season, this trend was observed at all study sites (Figure 6a). Upper littoral zone showed lowest density while middle littoral zone presented the highest value at all the sites (Figure 25 to 28). The population density values were variable from 0.51 no/0.25m^2 to 0.74 no/0.25m^2 (Fig. 13). The ANOVA test indicated that the four sites were no significantly difference in density values (Table 5).

Population abundance

Turbo intercostalis was the most abundant species and was present throughout the year, with very low in summer. Abundance values were significantly higher at Dwarka in post-monsoon season. Middle and lower littoral zone had high abundance values and were little bit similar at all sampling sites, but showed different seasonal trends (Figure 25 to 28). The abundance values increased remarkably and reached peak values during post-monsoon season and then remained at intermediate level till the monsoon at all the sampling sites. The abundance values fluctuated between 1.11 no/0.25m^2 and 1.38 no/0.25m^2. However, there was no significant difference in the frequency values were observed (Table 5). This species preferred to dwell at the middle littoral zone but during the study this species found at all littoral zone (Figure 25 to 28).

Population frequency

The population frequency of this snail changed through the year at all sites. In both post-monsoon and winter season frequency values were 52.22 no/0.25m^2 to 56.67 no/0.25m^2 and 50.00 no/0.25m^2 to 56.67 no/0.25m^2 respectively. In contrast, during summer season only 44.44 no/0.25m^2 to 47.78 no/0.25m^2 were found. The population frequency values were highly variable at Mangrol (44.44 no/0.25m^2 to 56.67no/0.25m^2) while Dwarka (44.44 no/0.25m^2 to 54.44 no/0.25m^2) and Kodinar (45.56 no/0.25m^2 to 55.56 no/0.25m^2) have a narrow range of frequency values found throughout the study period. The frequency value at Veraval varies between 47.78 no/0.25m^2 and 56.67 no/0.25m^2 but the fluctuations were parallel at all the study sites. The frequency values found to be higher in middle littoral zone followed by lower littoral zone and least vales were found in upper littoral zone at all the sites (Figure 25 to 28). The values remained higher at Veraval during winter, summer and monsoon season than the other sites but in case of post-monsoon season, values remained higher at Mangrol site. There was not any statistically significant difference found between all sampling sites (Table 5).

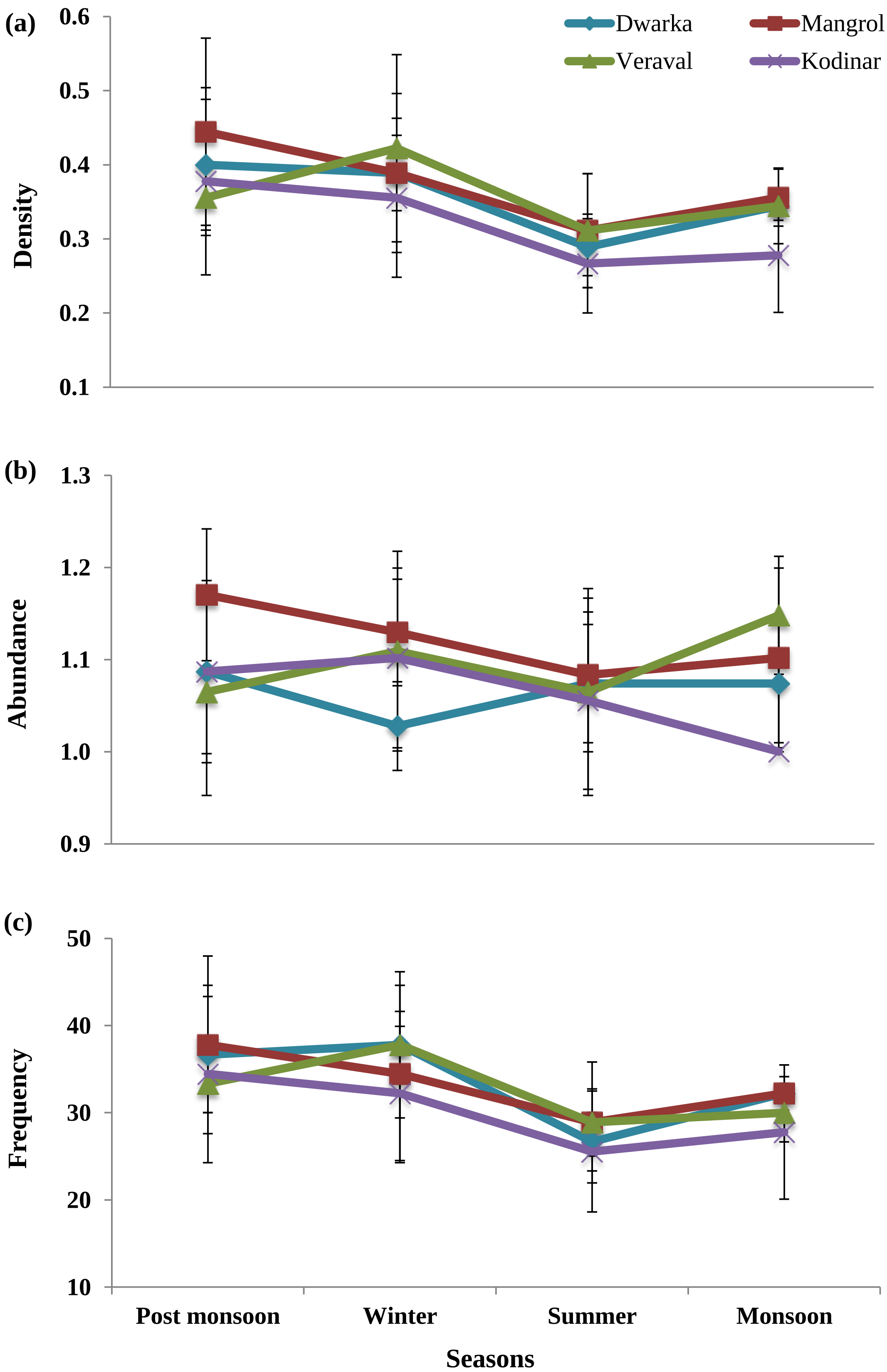

Figure 2. Seasonal variation in various ecological attributes of *Mancinella bufo* at four different sampling sites (Values expressed are mean ± SD).

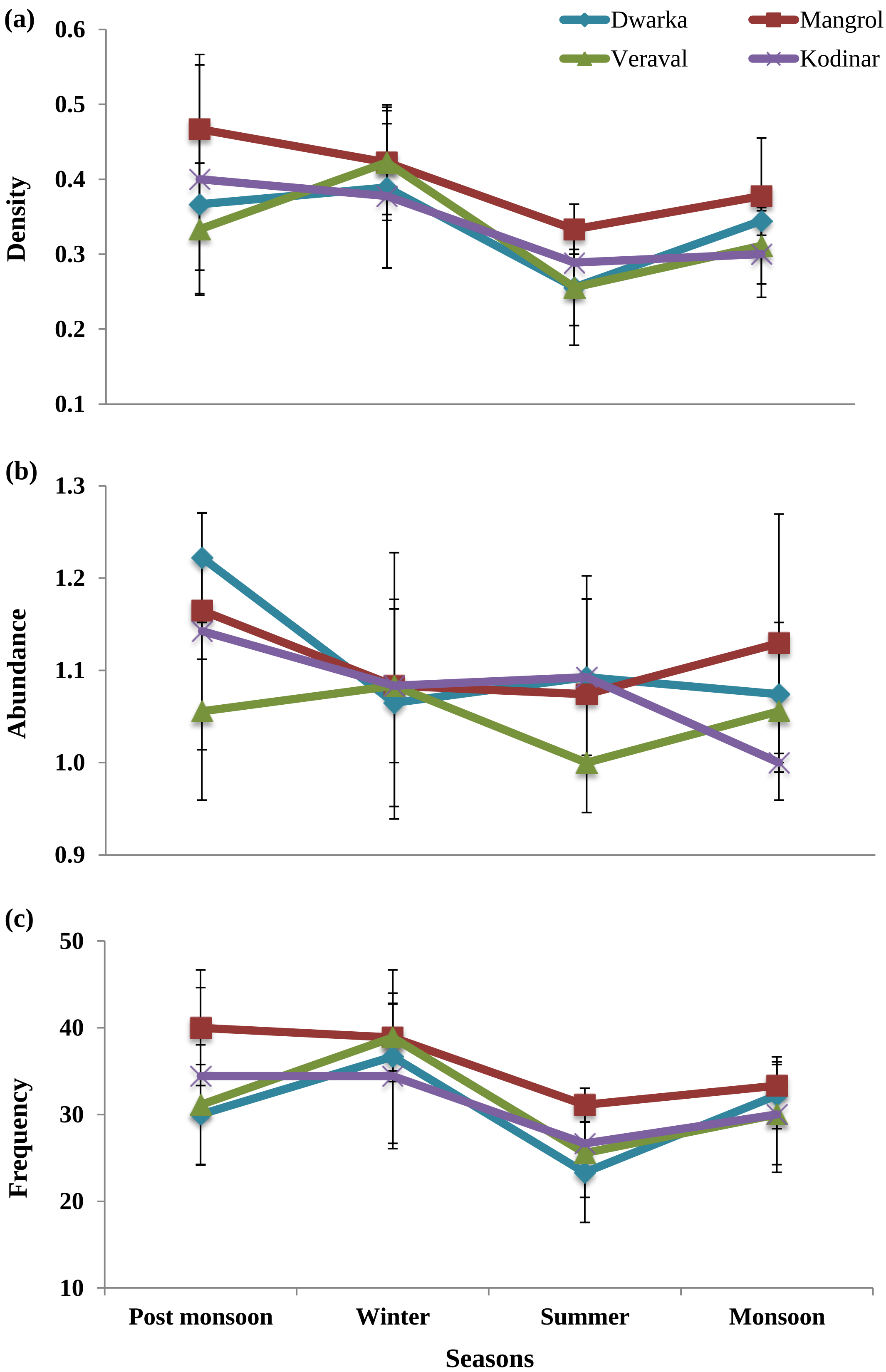

Figure 3. Seasonal variations in various ecological attributes of *Conus miliaris* at four different sampling sites (Values expressed are mean ± SD).

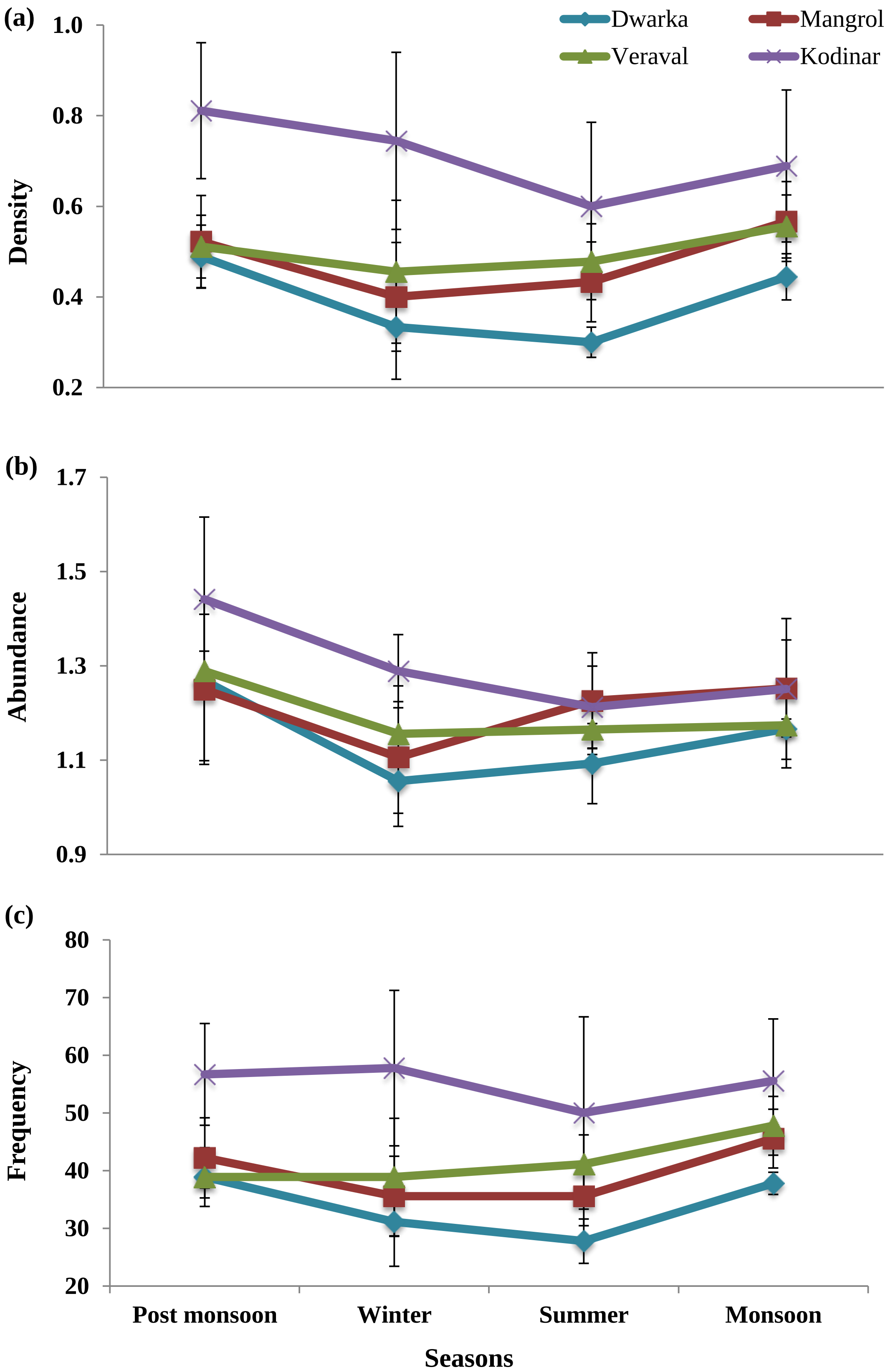

Figure 4. Seasonal variations in various ecological attributes of *Trochus radiatus* at four different sampling sites (Values expressed are mean ± SD).

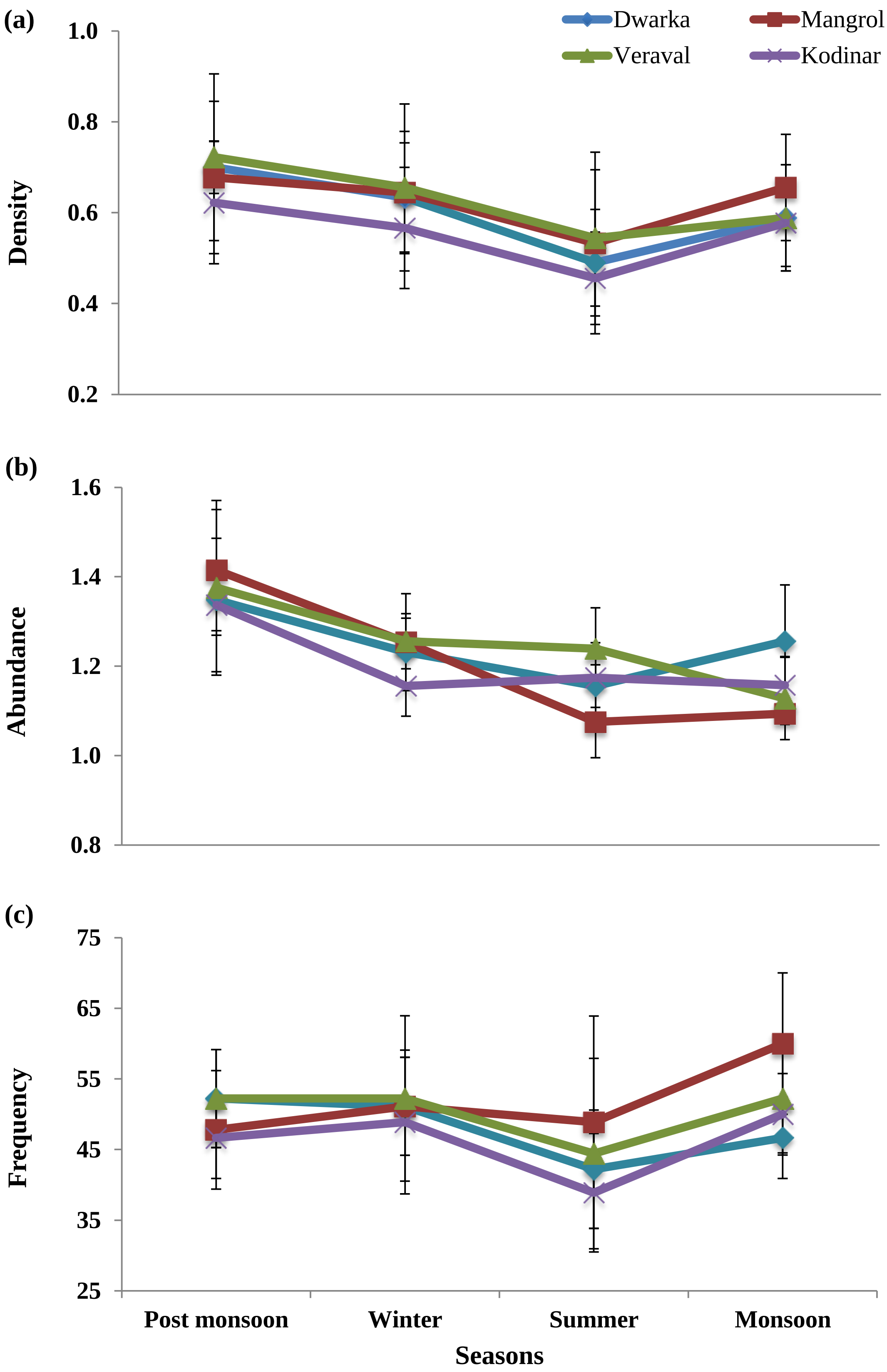

Figure 5. Seasonal variations in various ecological attributes of *Turbo coronetus* at four different sampling sites (Values expressed are mean ± SD).

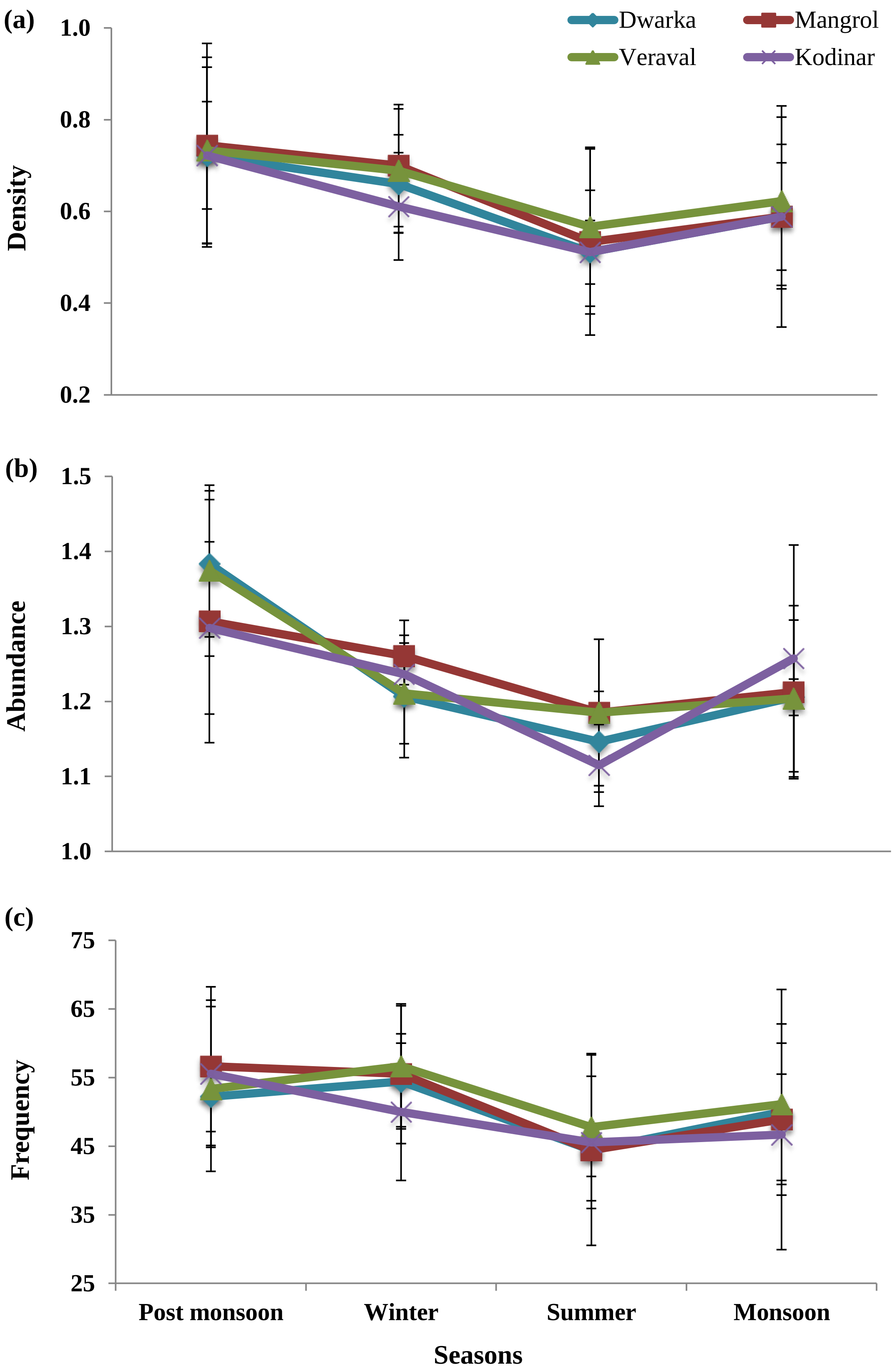

Figure 6. Seasonal variations in various ecological attributes of *Turbo intercoastalis coronetus* at four different sampling sites (Values expressed are mean ± SD).

4.7.6. *Nerita albicella*

Population density

Population density values of this species showed clear seasonal trend. Density values reached maximum during post-monsoon season and then decreased during winter to summer and then remained at intermediate level during monsoon season. These seasonal fluctuations in population density were similar at all the study sites (Figure 7a). The higher density values were recorded at Dwarka and lower values were recorded at Mangrol in most of the seasons. Density was ranged from 0.21 no/0.25m^2 to 0.52 no/0.25m^2. Its general pattern of distribution showed the lowest values in lower littoral zone and the highest values in middle littoral zone (Figure 29 to 32). They did not show any significant spatial differences in density values (Table 5).

Population abundance

The abundance values were ranging from 1.00 no/0.25m^2 at Veraval to 1.48 no/0.25m^2 at Dwarka. The overall abundance pattern was not as clear as density pattern. An abundance value comprises narrow range of fluctuation. In general, this species was twice more abundant at Dwarka. Abundance values increased from upper to the middle littoral zone of intertidal belt but then decreased towards lower levels (Figure 29 to 32). The values were first decreased during post-monsoon to summer and then remained fairly stable to monsoon season at Dwarka and Veraval, but in case of Mangrol values were slightly increased during summer season while at Kodinar values showed slight fluctuation in seasonal range. However, there were no significant differences found in spatial changes (Table 5).

Population frequency

The population frequency values were quite uniform with the changes of season. At Mangrol, Veraval and Kodinar, they were distributed in a narrow range with seasonal changes, but at Dwarka, showed irregularities. A significant difference of the values was not observed (Table 5). The minimum values were observed during summer for all the sites. Like density frequency values were also found to be higher in middle littoral zone at all the sampling sites (Figure 29 to 32). Frequency values showed much fluctuation at Dwarka in the zonal distribution as compared to other sampling sites.

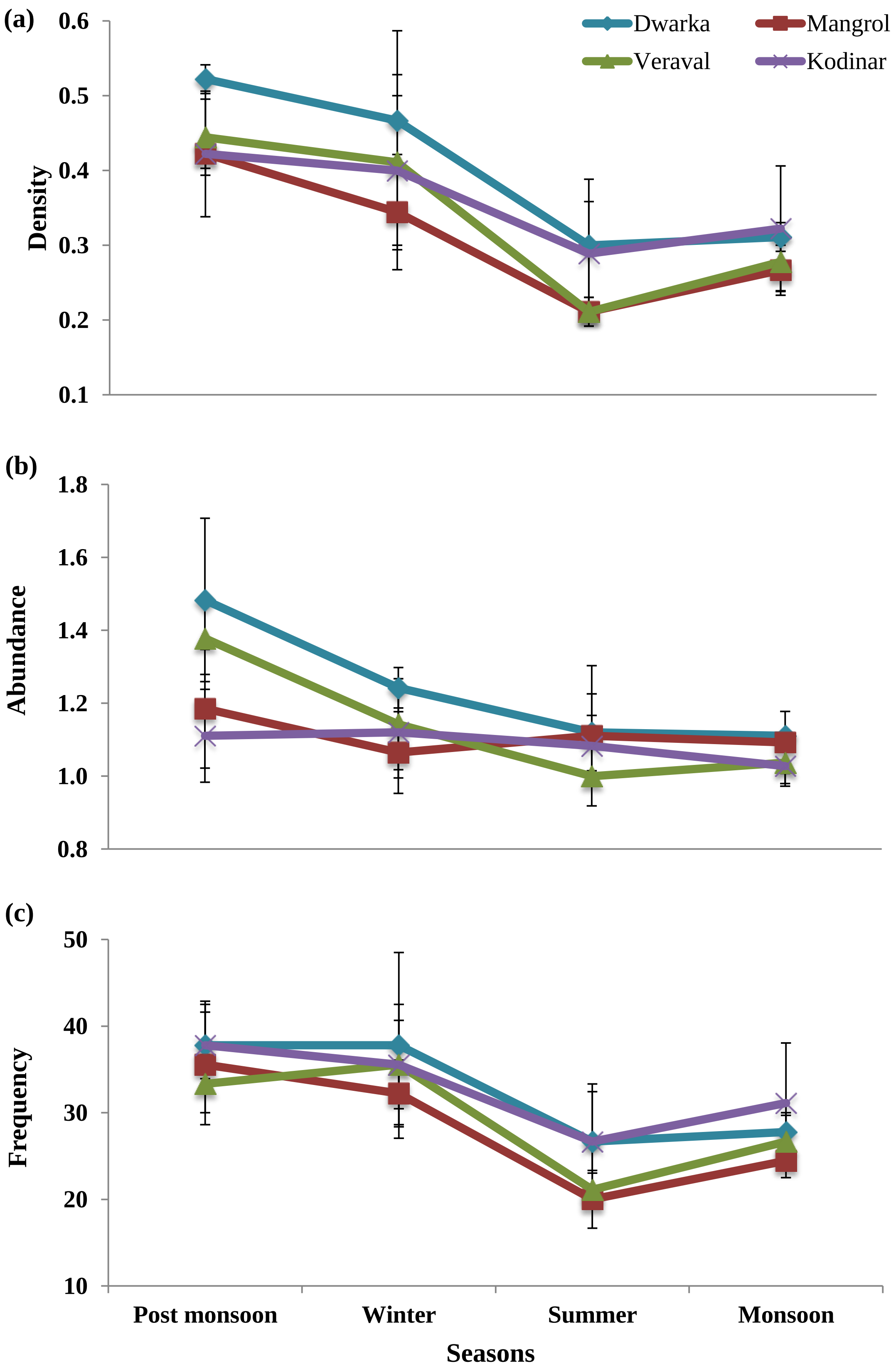

Figure 7. Seasonal variations in various ecological attributes of *Nerita albicilla coronetus* at four different sampling sites (Values expressed are mean ± SD).

4.7.7. *Rhinoclavis sinensis*

Population density

The gastropod mollusca, *Rhinoclavis sinensis* belonging to cerithidae family showed high density values during post-monsoon season. There were no major variations found among all the sampling sites in all the seasons except winter season. The highest density values were observed at Dwarka and lowest at Kodinar in most of the seasons (Figure 8a). The density values showed higher in middle littoral zone and lowest in lower littoral zone during all the seasons at the study area (Figure 33 to 36). Density values at Mangrol and Veraval did not show any differences, it remained parallel during all seasons. However, there was no significant difference found between all the sampling sites (Table 5).

Population abundance

The results of abundance values showed definite pattern during the seasons. Abundance values recorded higher in post-monsoon season, then after decreased during winter to summer and then slightly increased during monsoon at all the sampling sites (Figure 8b). Zonal pattern of abundance value showed high in middle littoral zone at Dwarka and Mangrol, but in case of Veraval and Kodinar abundance values were equally distributed in each zone (Figure 33 to 36). Values showed narrow range of fluctuation between the sampling sites. The range of abundance values recorded 1.12 no/0.25m^2 to 1.54 no/0.25m^2. There was no any significant spatial fluctuation (Table 5).

Population frequency

Frequency values showed similar seasonal trend at all study sites. The frequency values ranged from 30.30 no/0.25m^2 to 43.30 no/0.25m^2 in upper littoral zone, 33.3 no/0.25m^2 to 50.0 no/0.25m^2 in middle littoral zone and 23.30 no/0.25m^2 to 53.3 no/0.25m^2 in lower littoral zone. In this study little fluctuation was found between seasons. However, the lowest values were recorded during summer season at all the sampling sites. The frequency values showed a much closer value during post-monsoon and winter seasons (Figure 8c). There was no significant difference found in population frequency values (Table 5). The maximum value of frequency was found at Dwarka sampling site.

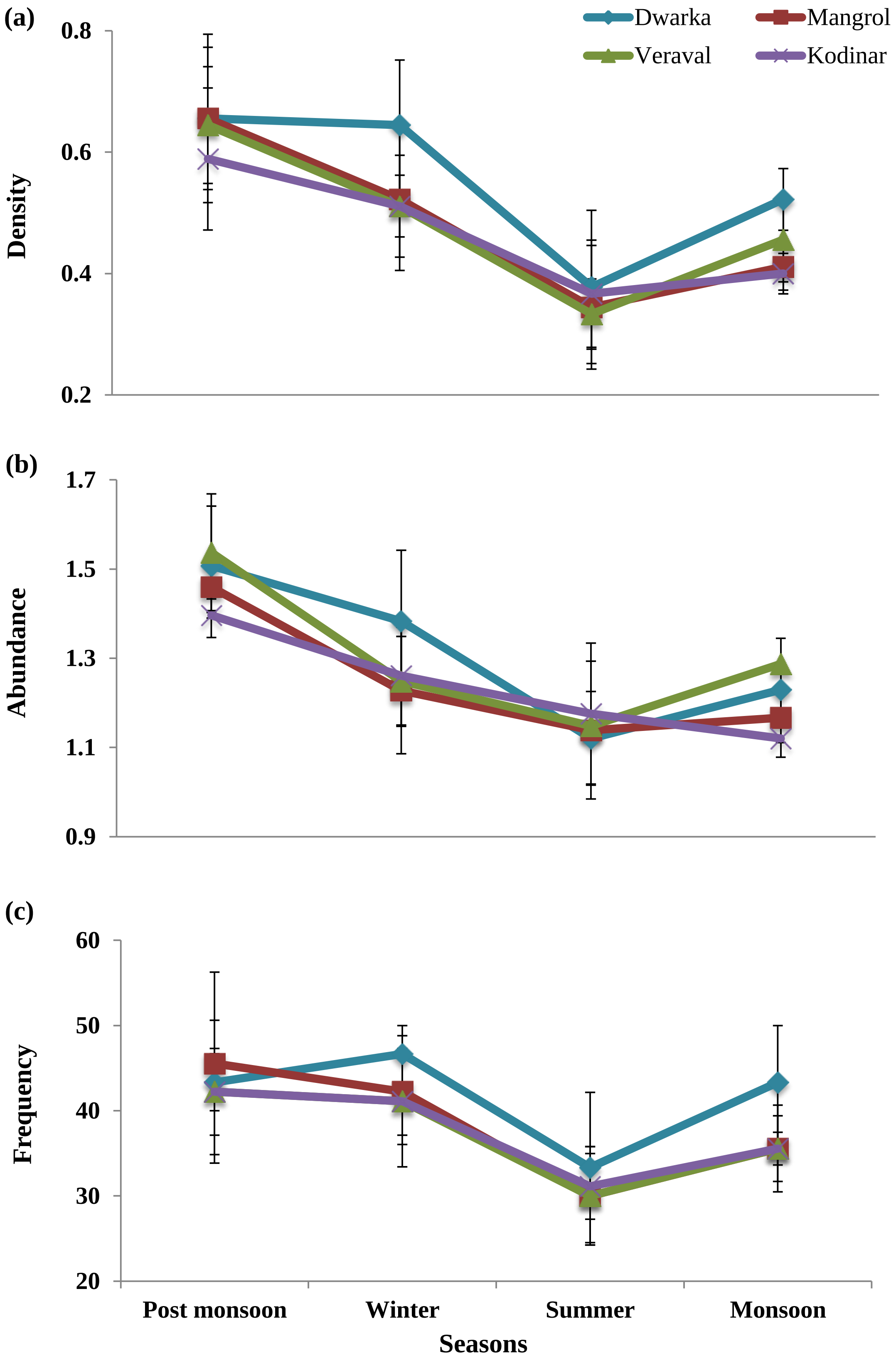

Figure 8. Seasonal variations in various ecological attributes of *Rhinoclavis sinensis* at four different sampling sites (Values expressed are mean ± SD).

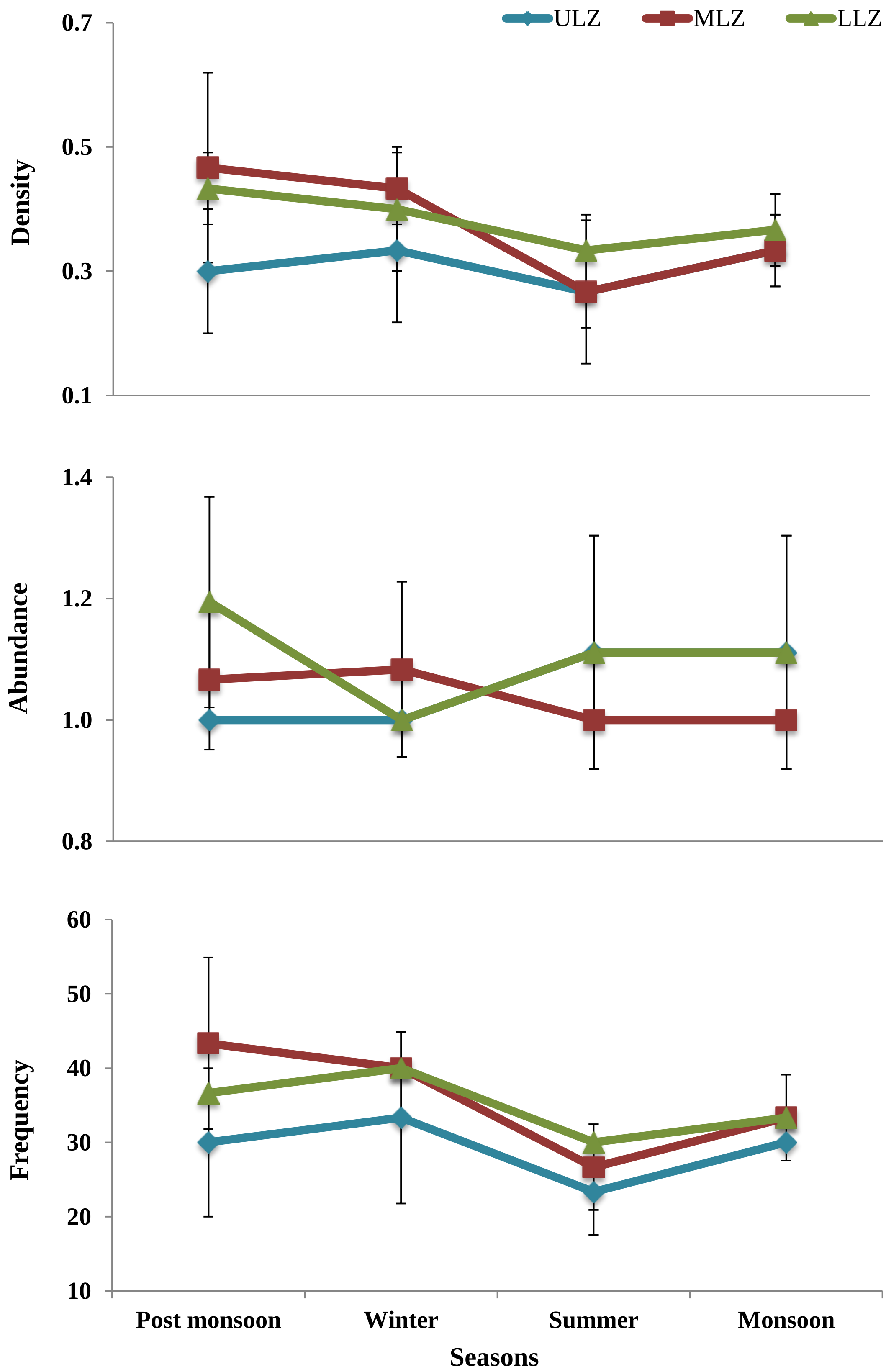

Figure 9. Seasonal variations in various ecological attributes values (0.25 m^{-2}) of *Mancinella bufo* in different littoral zones at sampling site Dwarka.

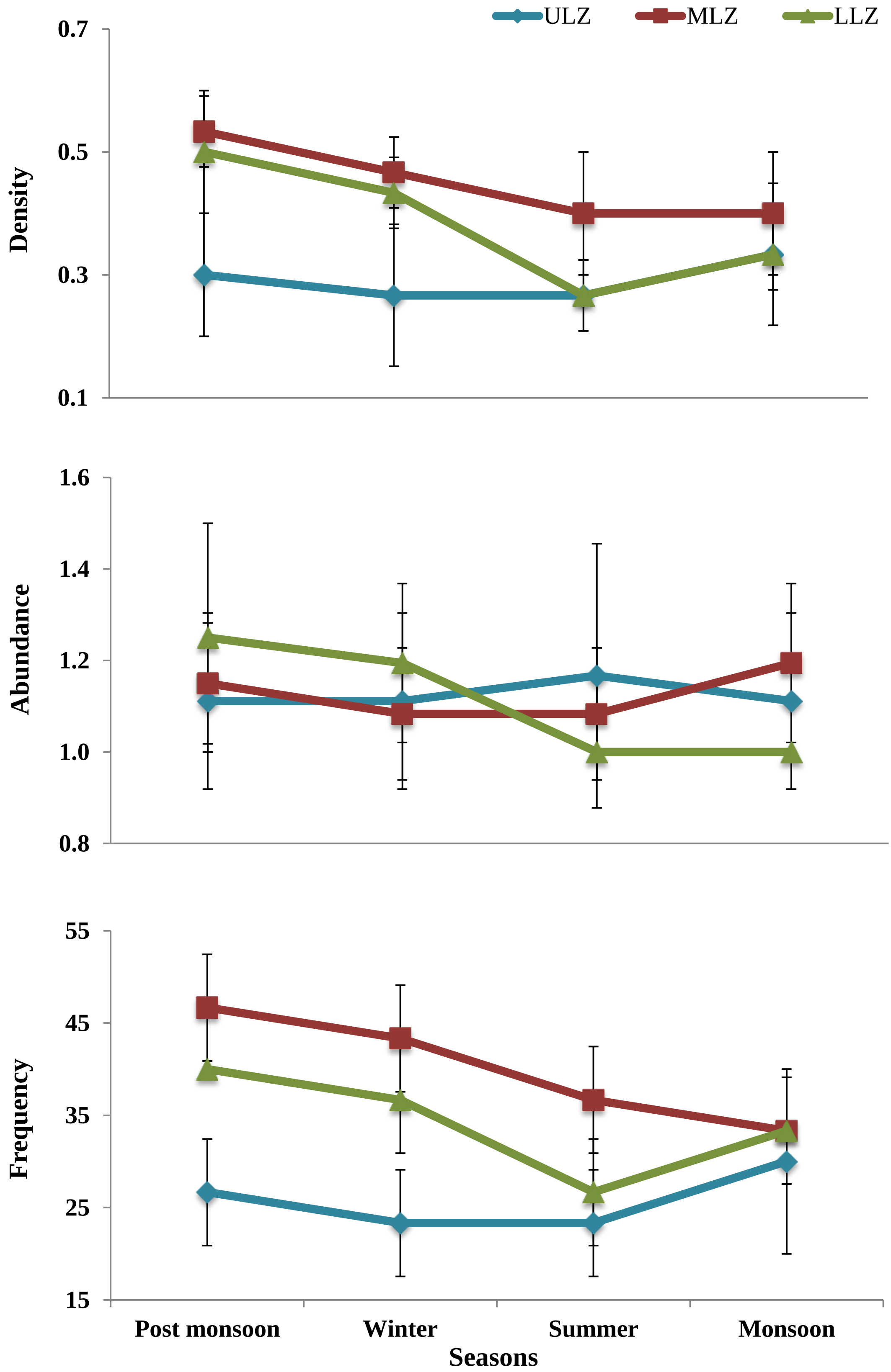

Figure 10. Seasonal variations in various ecological attributes values (0.25 m^{-2}) of *Mancinella bufo* in different littoral zones at sampling site Mangrol.

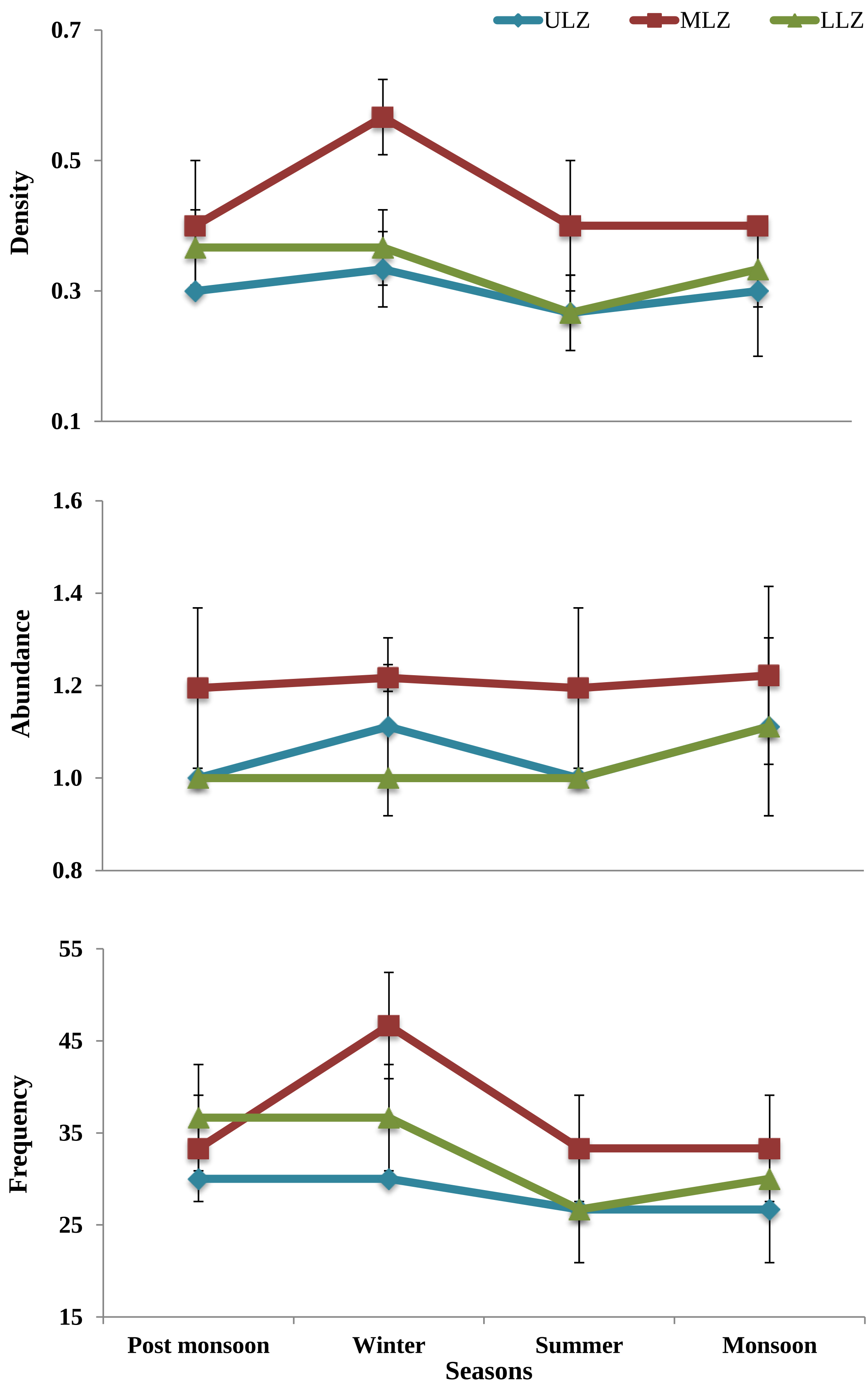

Figure 11. Seasonal variations in various ecological attributes values (0.25 m^{-2}) of *Mancinella bufo* in different littoral zones at sampling site Veraval.

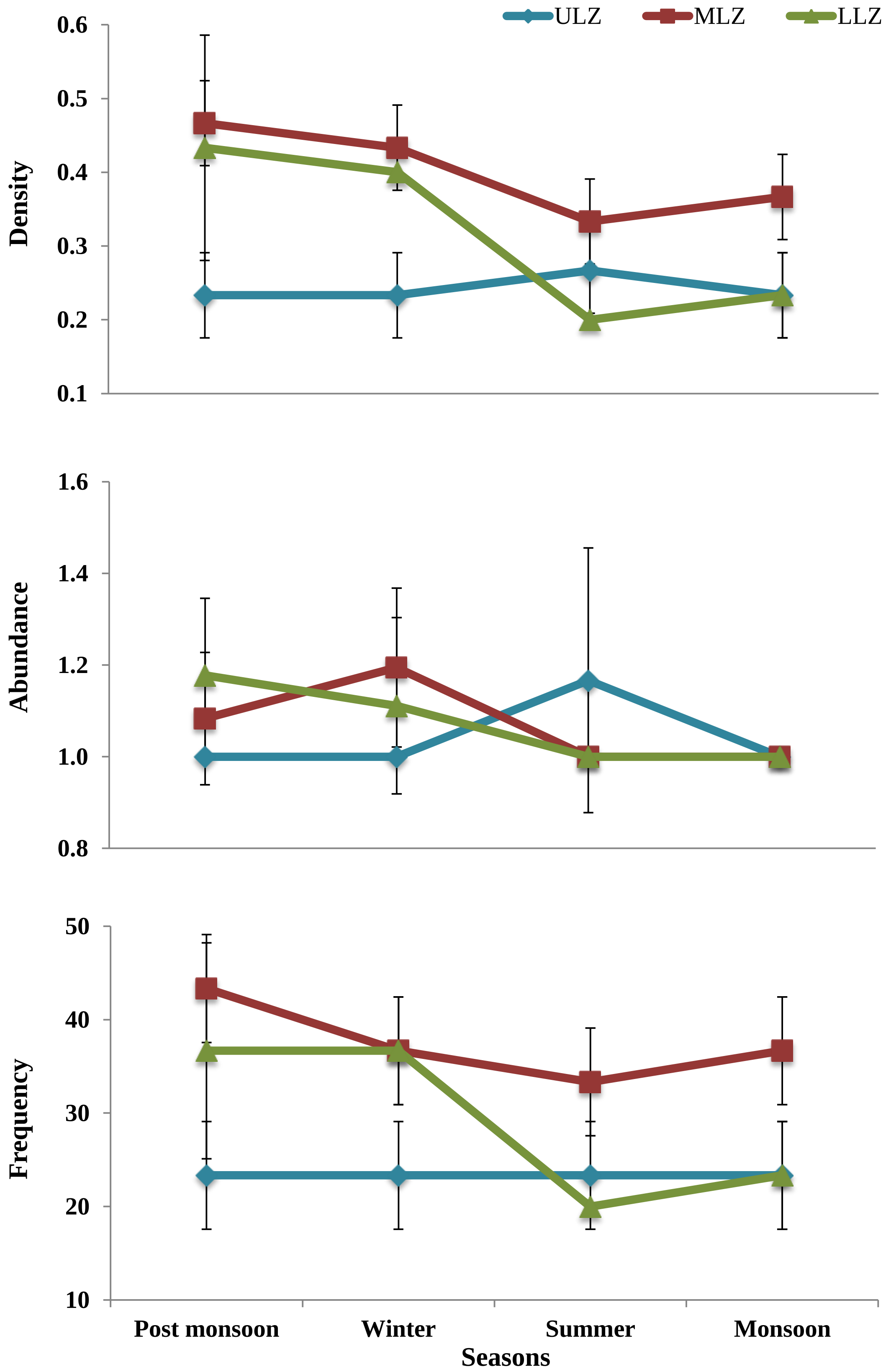

Figure 12. Seasonal variations in various ecological attributes values (0.25 m^{-2}) of *Mancinella bufo* in different littoral zones at sampling site Kodinar.

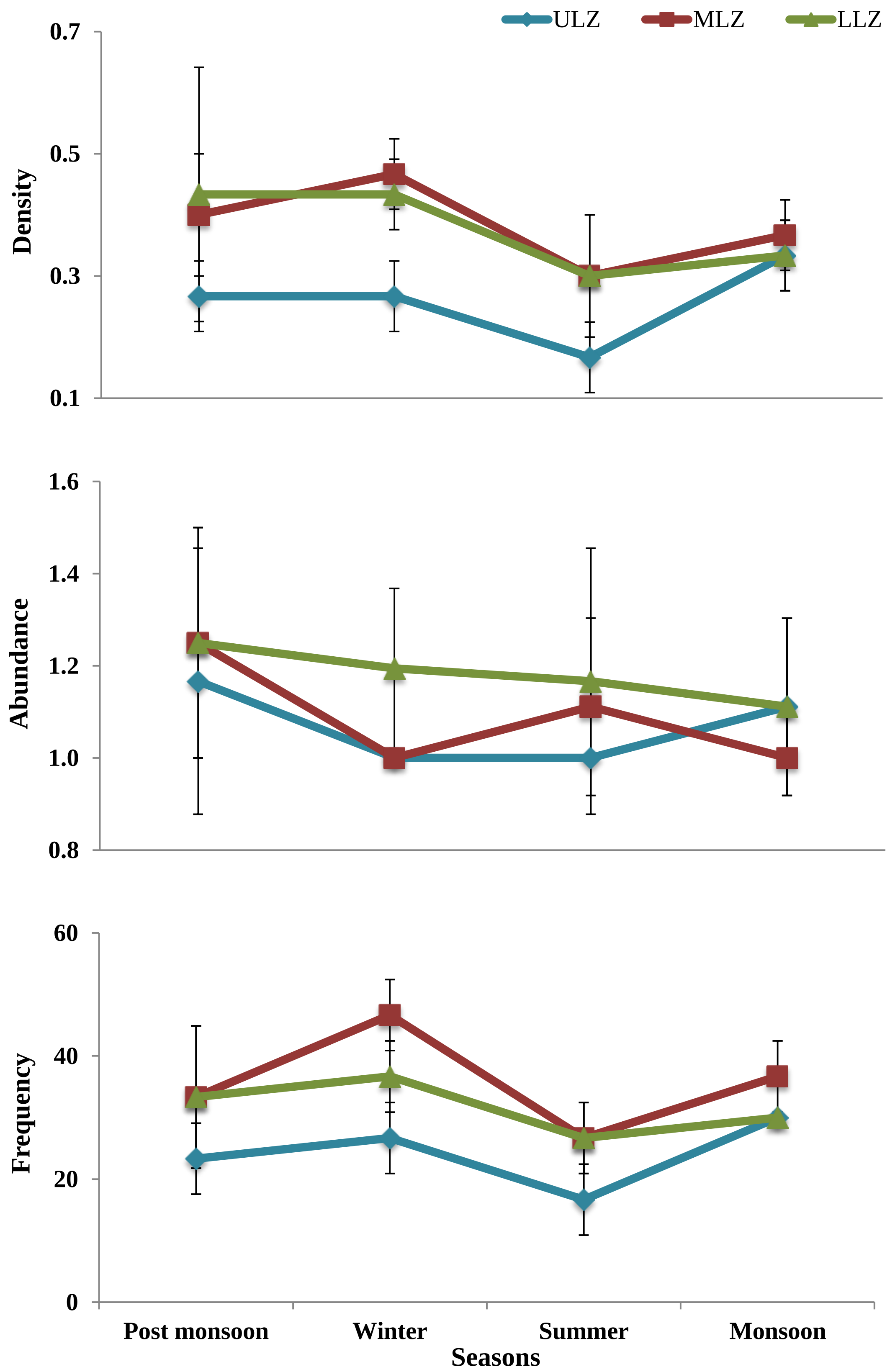

Figure 13. Seasonal variations in various ecological attributes values (0.25 m^{-2}) of *Conus miliaris* in different littoral zones at sampling site Dwarka.

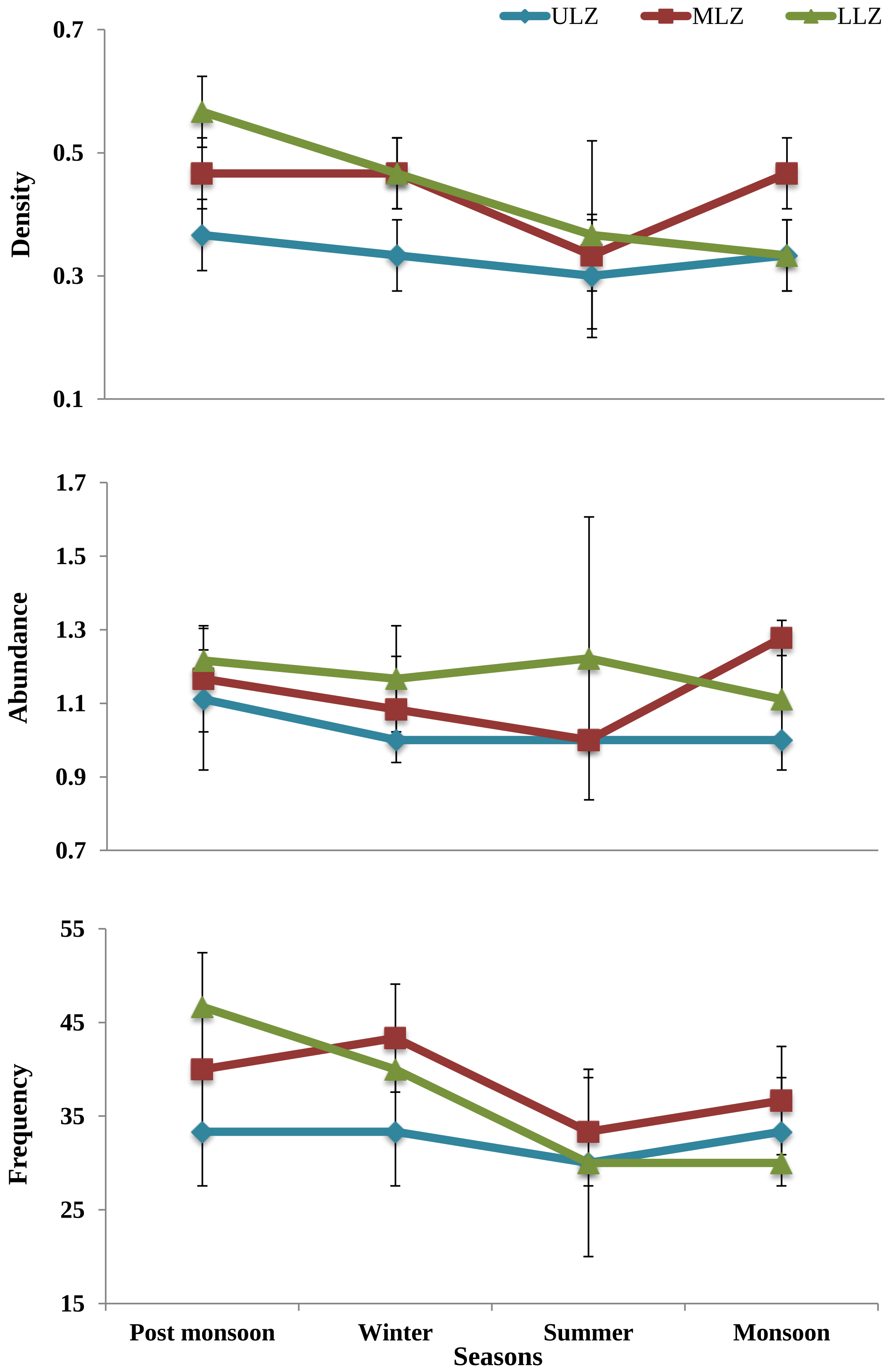

Figure 14. Seasonal variations in various ecological attributes values (0.25 m^{-2}) of *Conus miliaris* in different littoral zones at sampling site Mangrol.

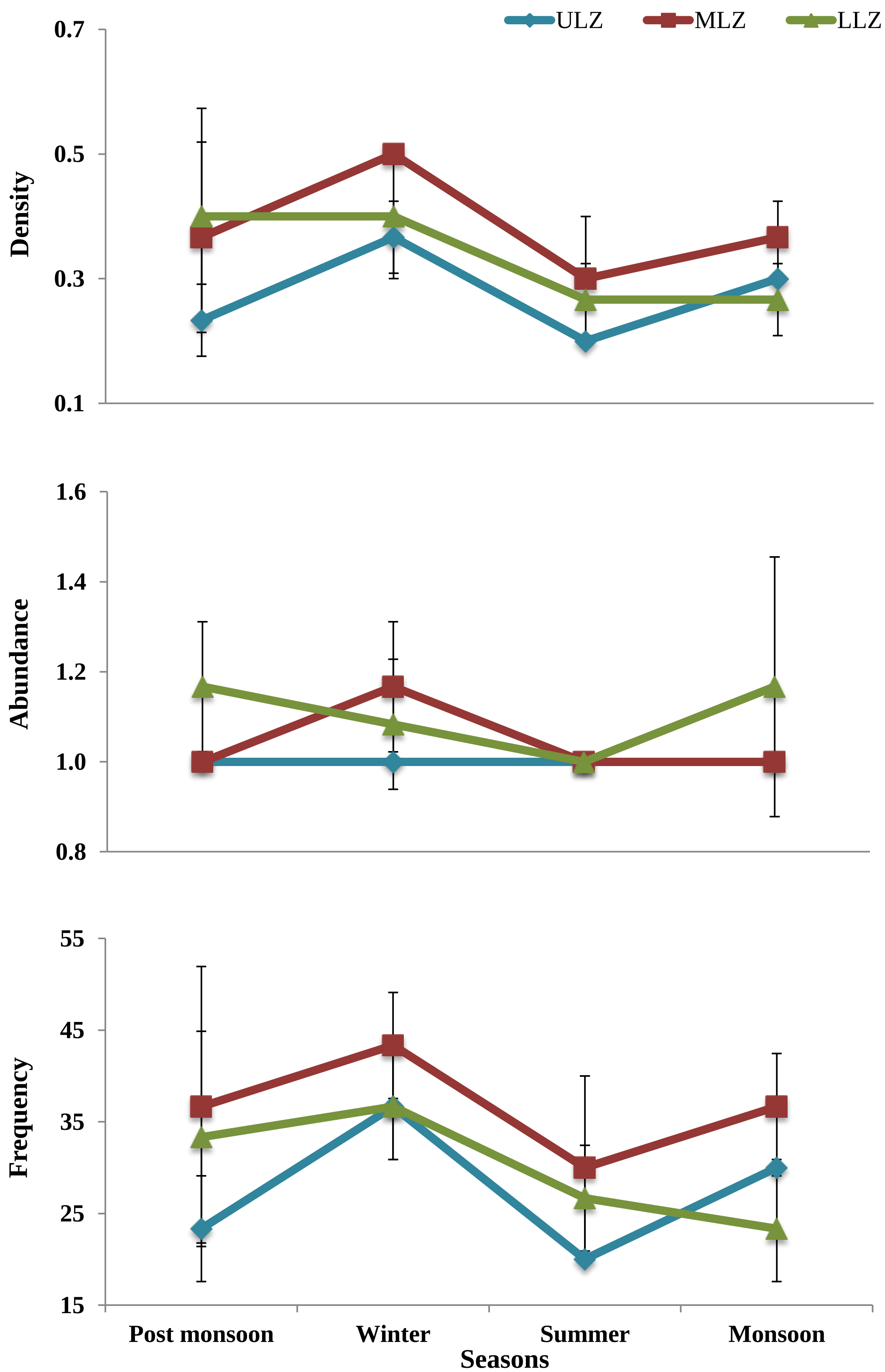

Figure 15. Seasonal variations in various ecological attributes values (0.25 m^{-2}) of *Conus miliaris* in different littoral zones at sampling site Veraval.

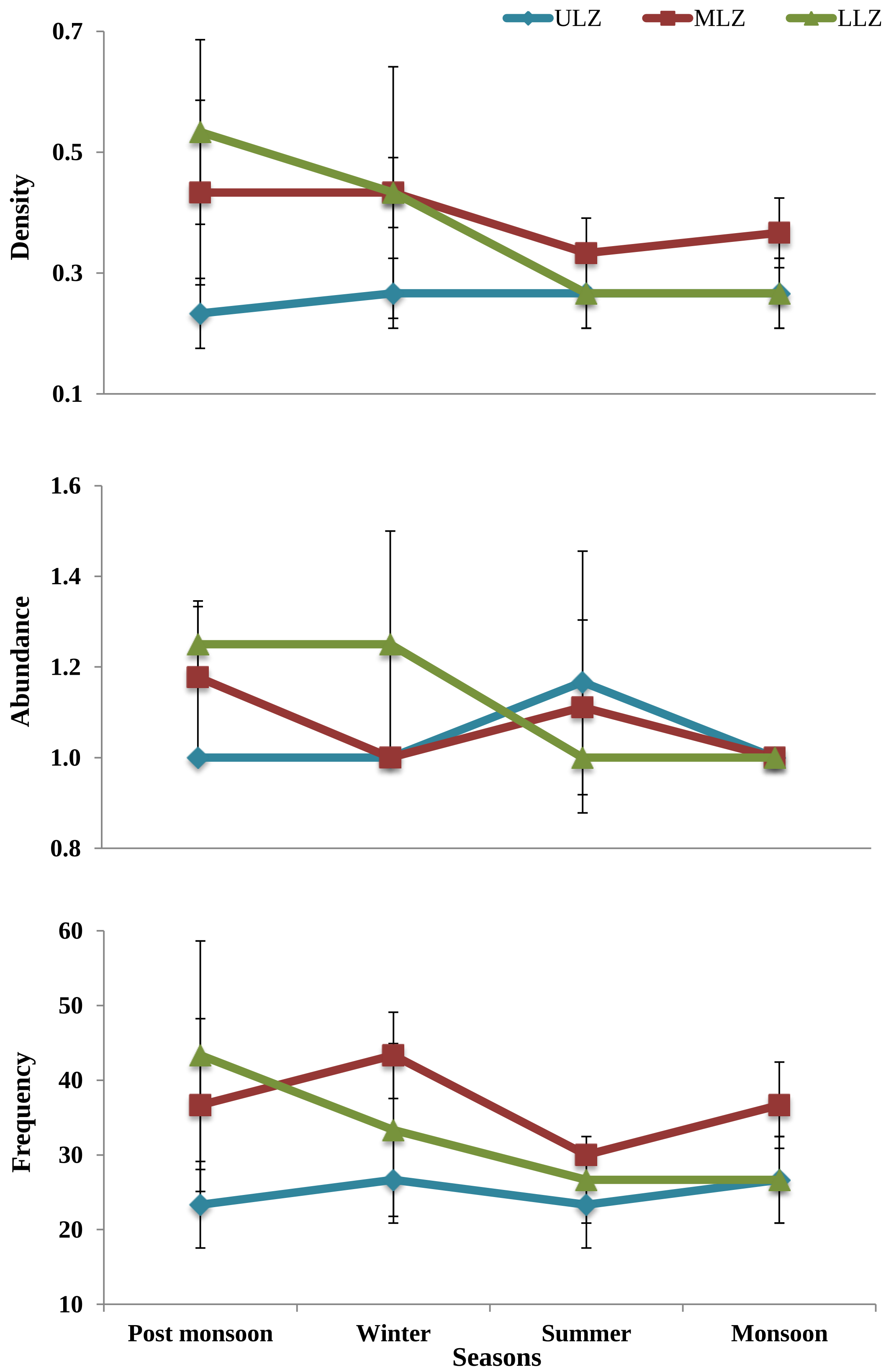

Figure 16. Seasonal variations in various ecological attributes values (0.25 m^{-2}) of *Conus miliaris* in different littoral zones at sampling site Kodinar.

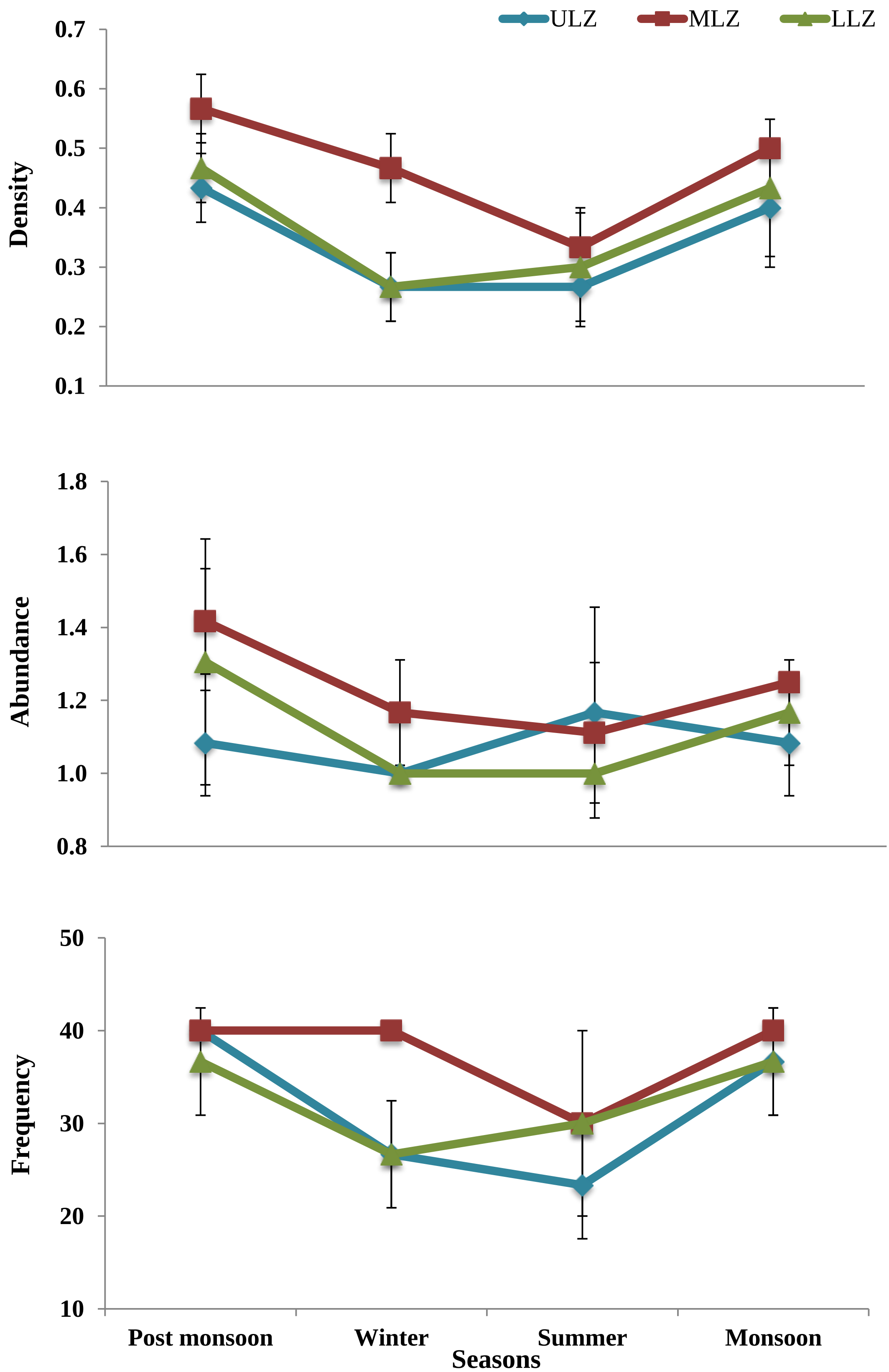

Figure 17. Seasonal variations in various ecological attributes values (0.25 m^{-2}) of *Trochus radiatus* in different littoral zones at sampling site Dwarka.

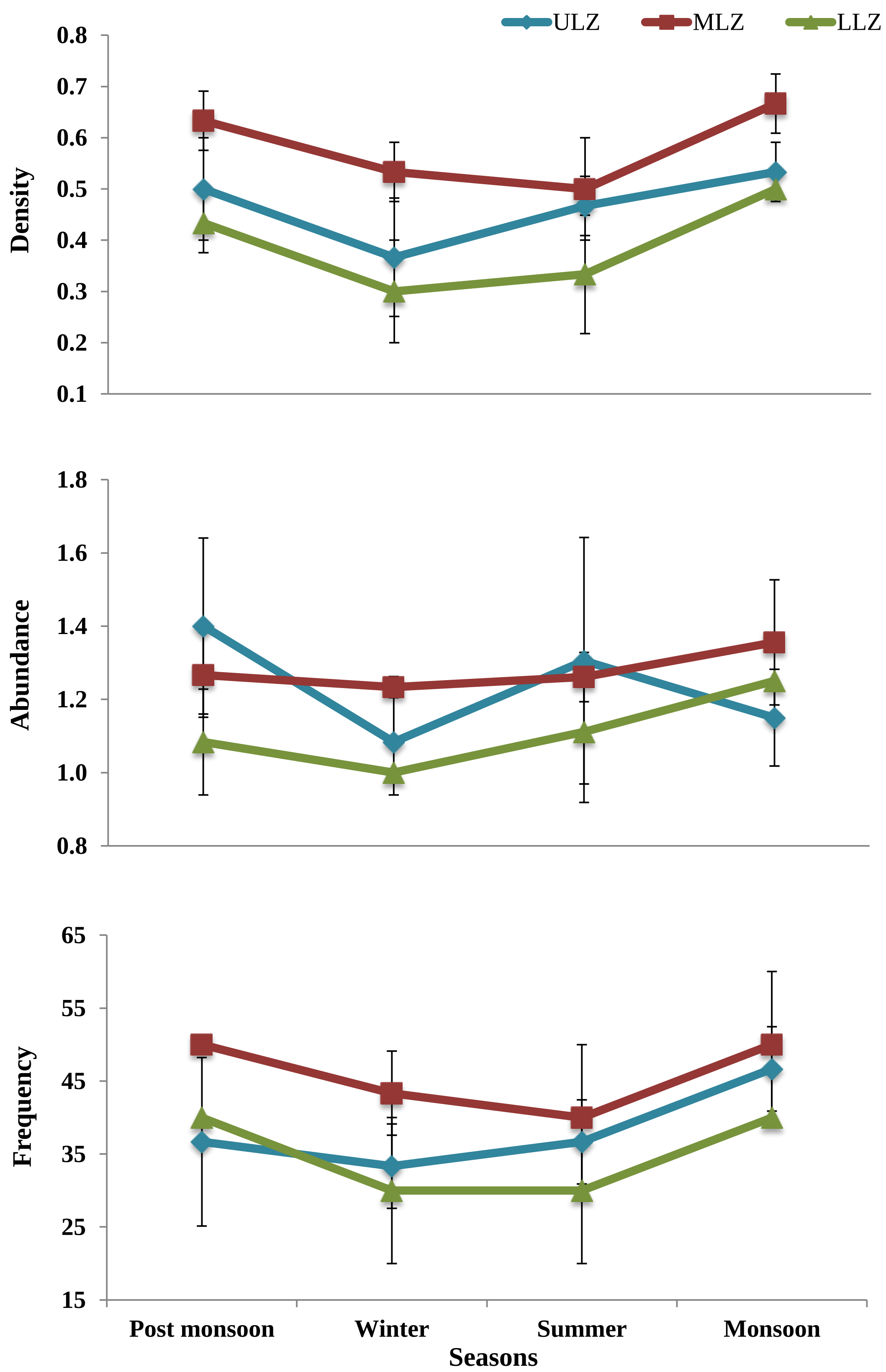

Figure 18. Seasonal variations in various ecological attributes values (0.25 m^{-2}) of *Trochus radiatus* in different littoral zones at sampling site Mangrol.

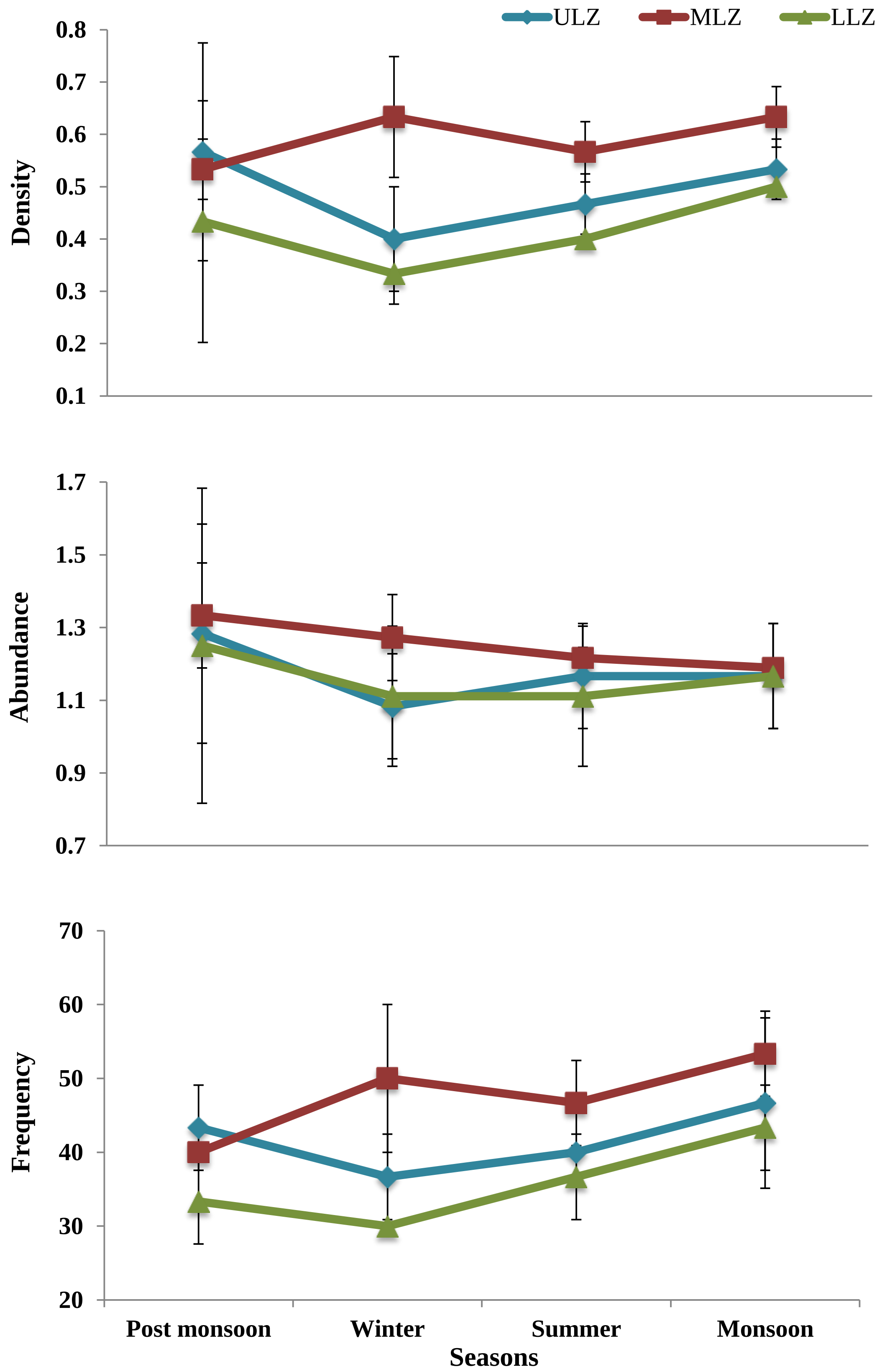

Figure 19. Seasonal variations in various ecological attributes values (0.25 m^{-2}) of *Trochus radiatus* in different littoral zones at sampling site Veraval.

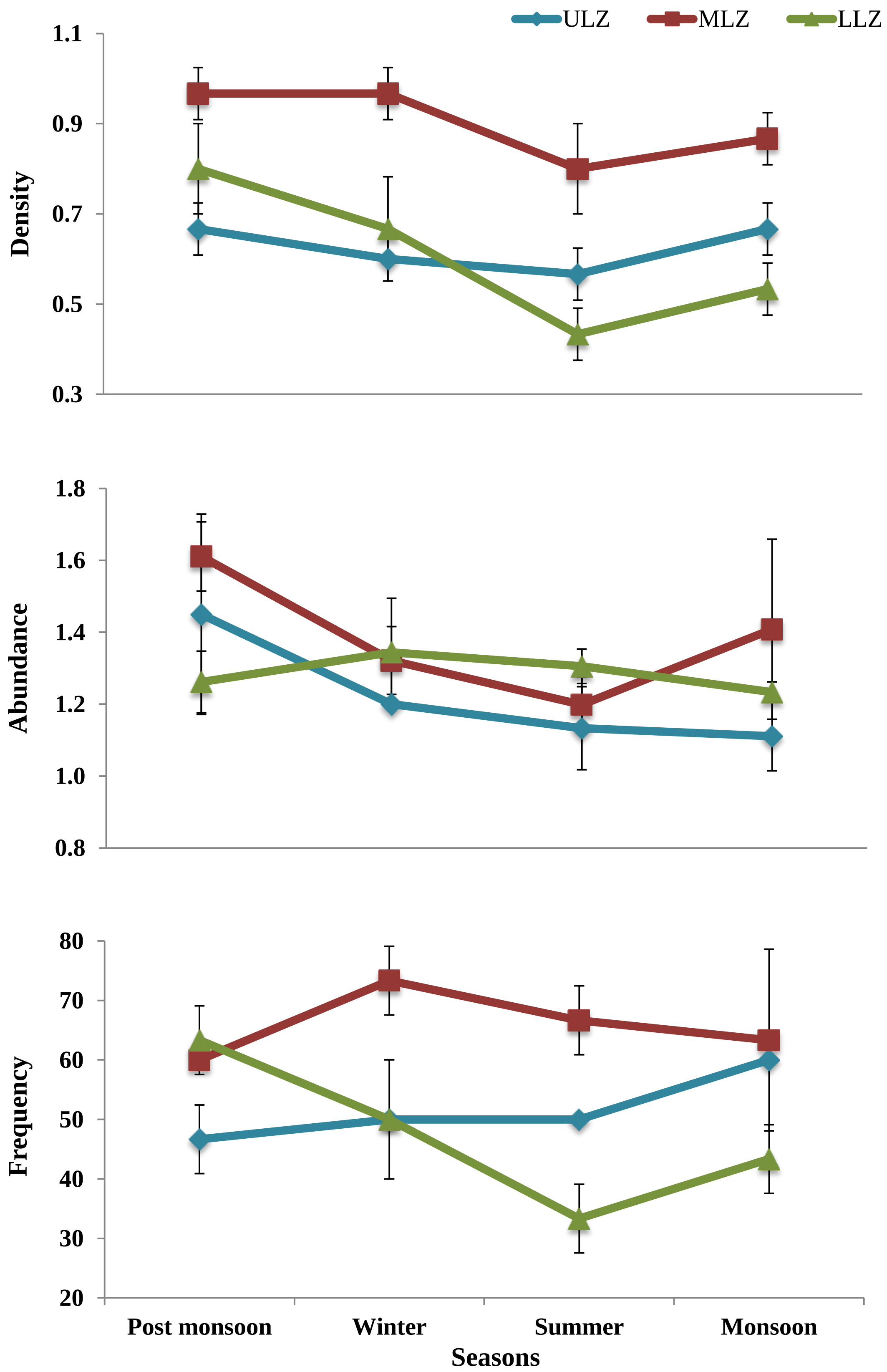

Figure 20. Seasonal variations in various ecological attributes values (0.25 m^{-2}) of *Trochus radiatus* in different littoral zones at sampling site Kodinar.

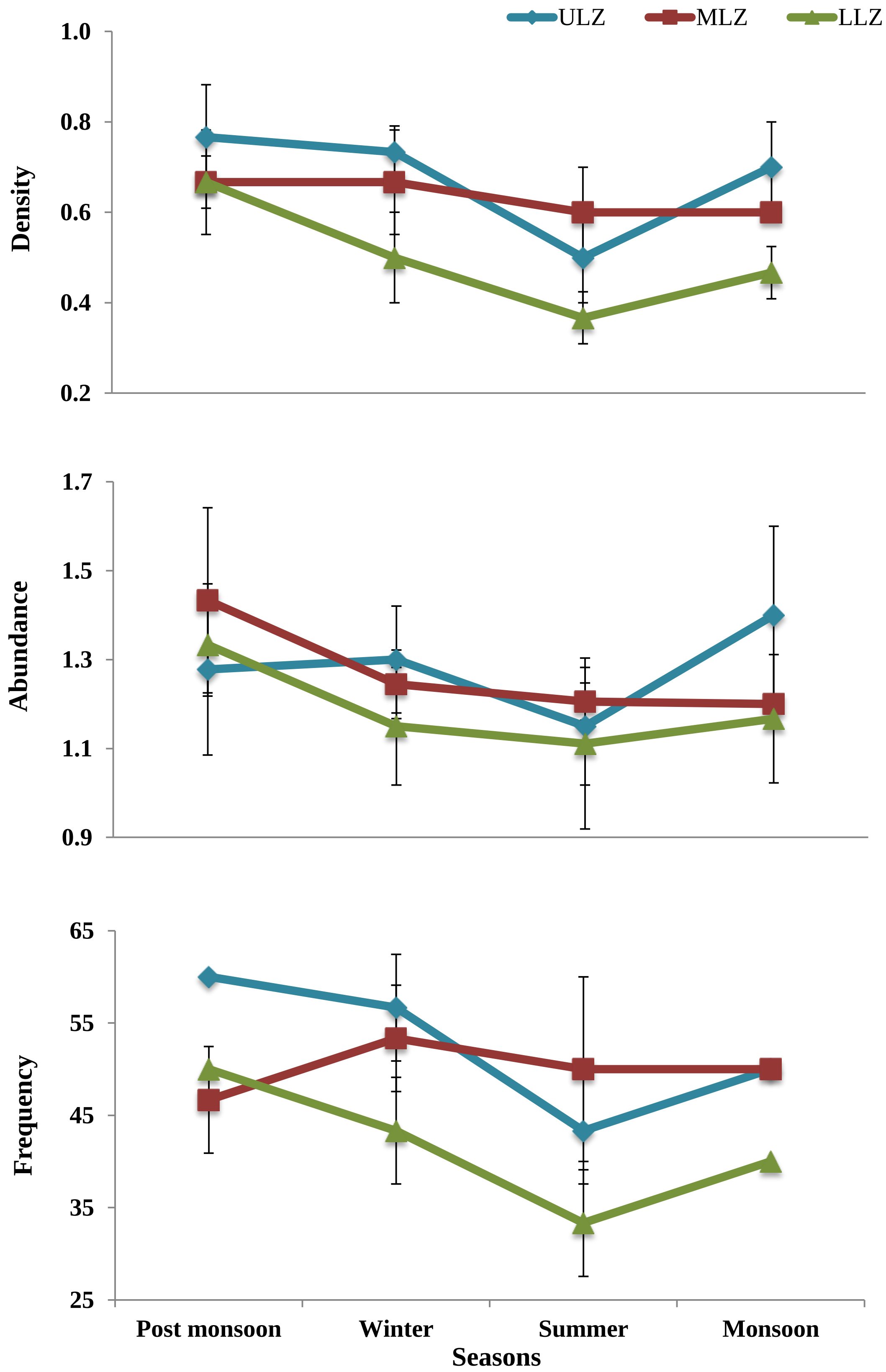

Figure 21. Seasonal variations in various ecological attributes values (0.25 m^{-2}) of *Turbo coronetus* in different littoral zones at sampling site Dwarka.

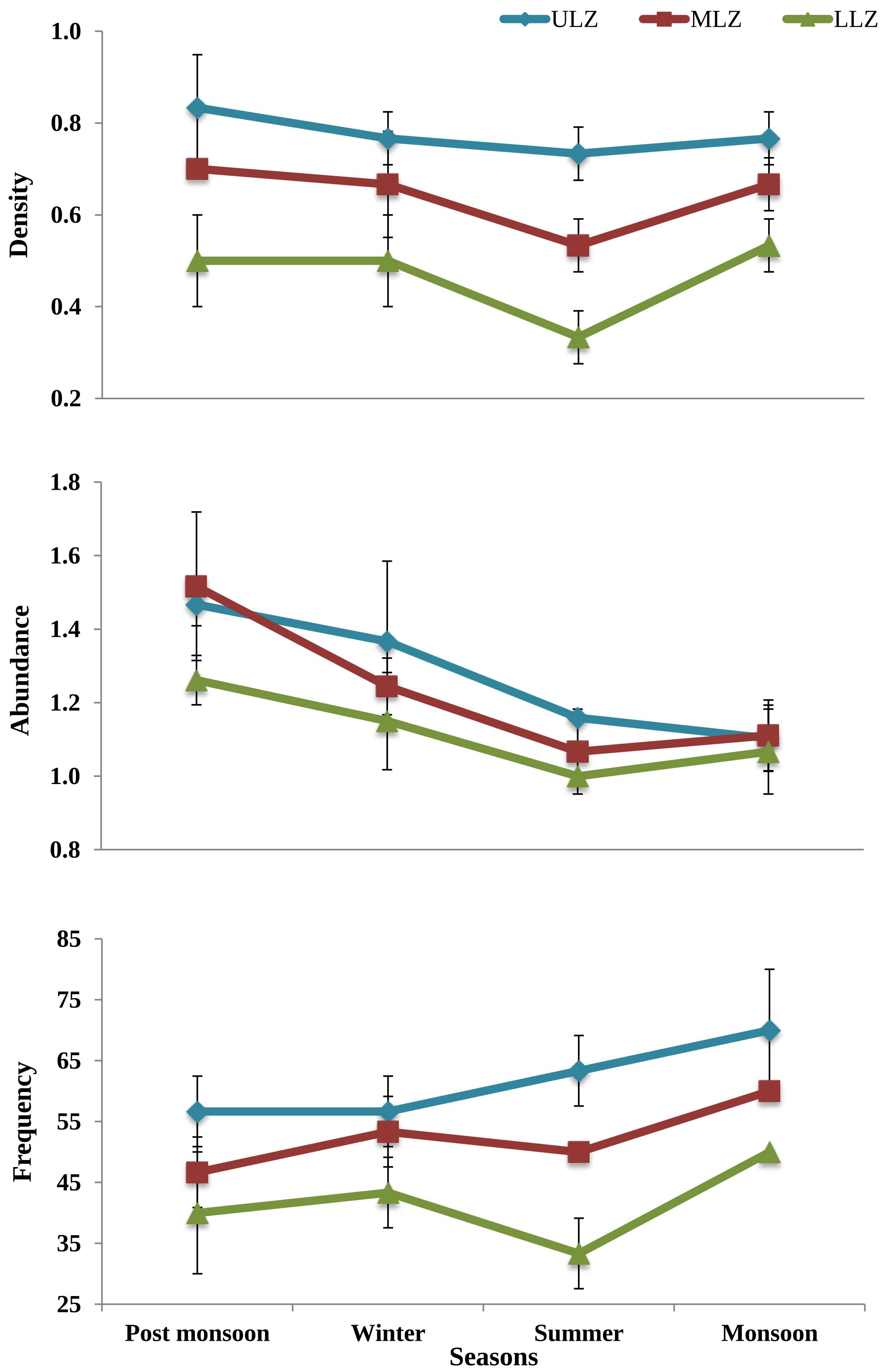

Figure 22. Seasonal variations in various ecological attributes values (0.25 m^{-2}) of *Turbo coronetus* in different littoral zones at sampling site Mangrol.

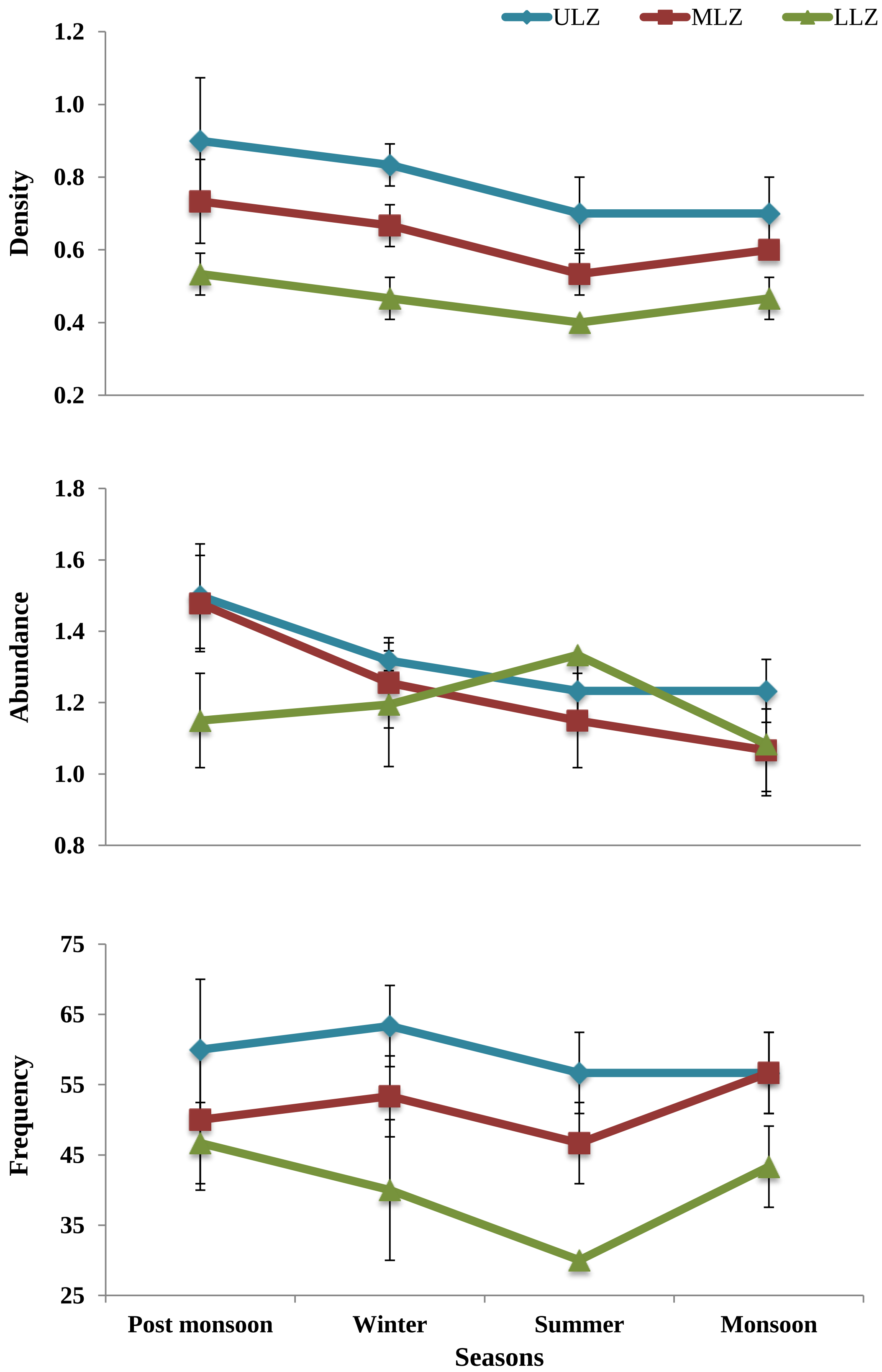

Figure 23. Seasonal variations in various ecological attributes values (0.25 m^{-2}) of *Turbo coronetus* in different littoral zones at sampling site Veraval.

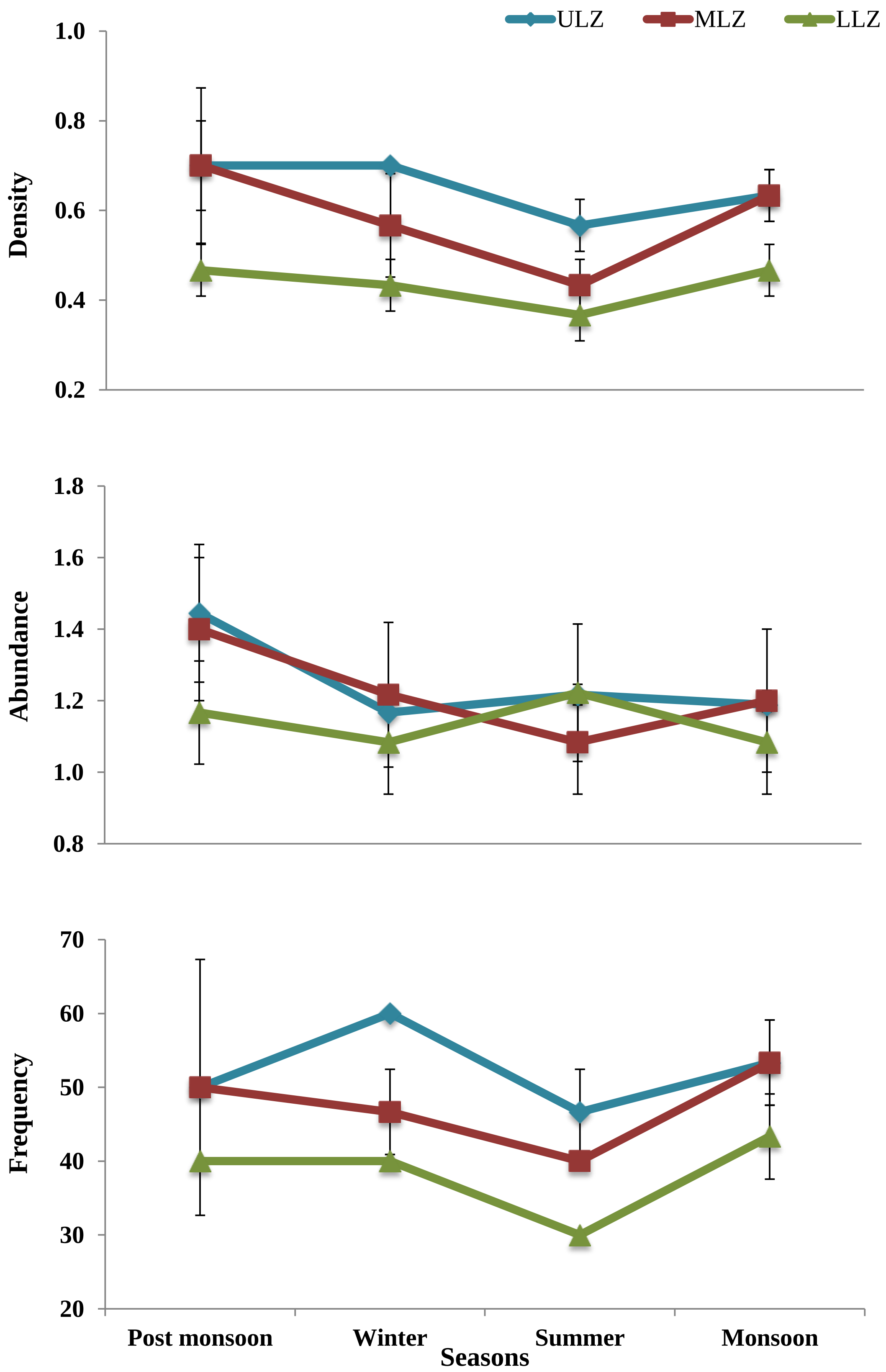

Figure 24. Seasonal variations in various ecological attributes values (0.25 m^{-2}) of *Turbo coronetus* in different littoral zones at sampling site Kodinar.

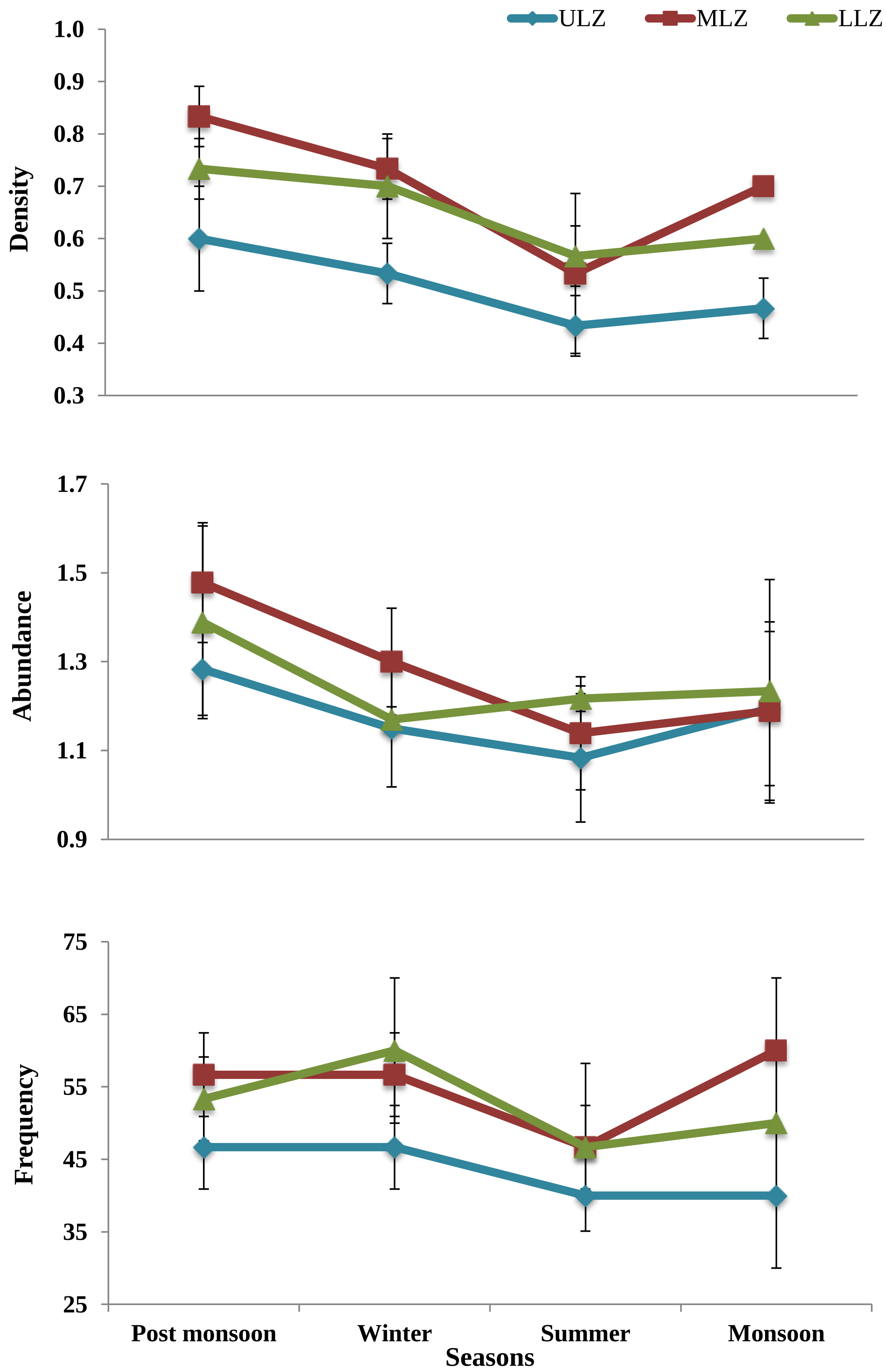

Figure 25. Seasonal variations in various ecological attributes values (0.25 m^{-2}) of *Turbo intercostalis* in different littoral zones at sampling site Dwarka.

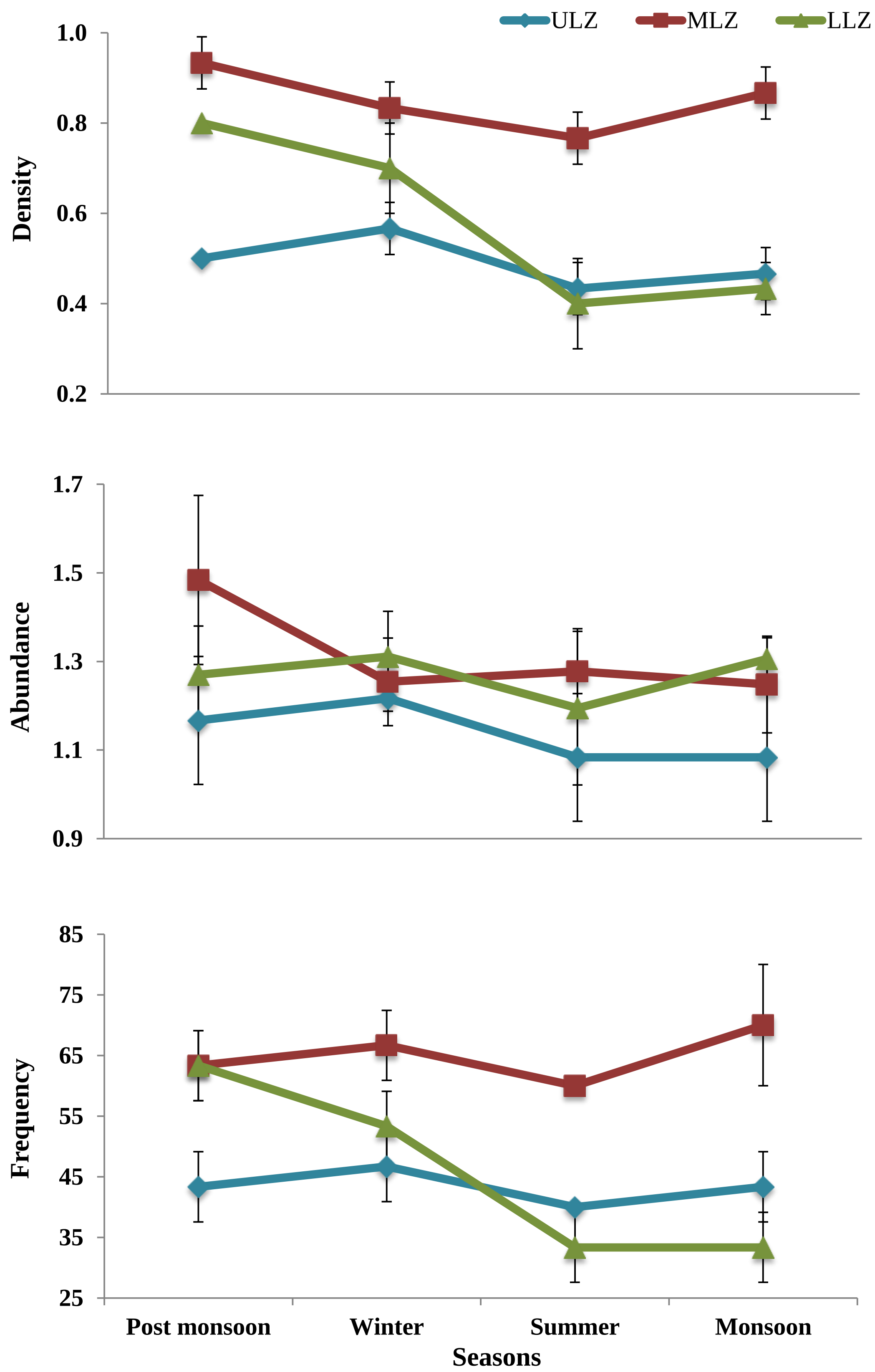

Figure 26. Seasonal variations in various ecological attributes values (0.25 m^{-2}) of *Turbo intercostalis* in different littoral zones at sampling site Mangrol.

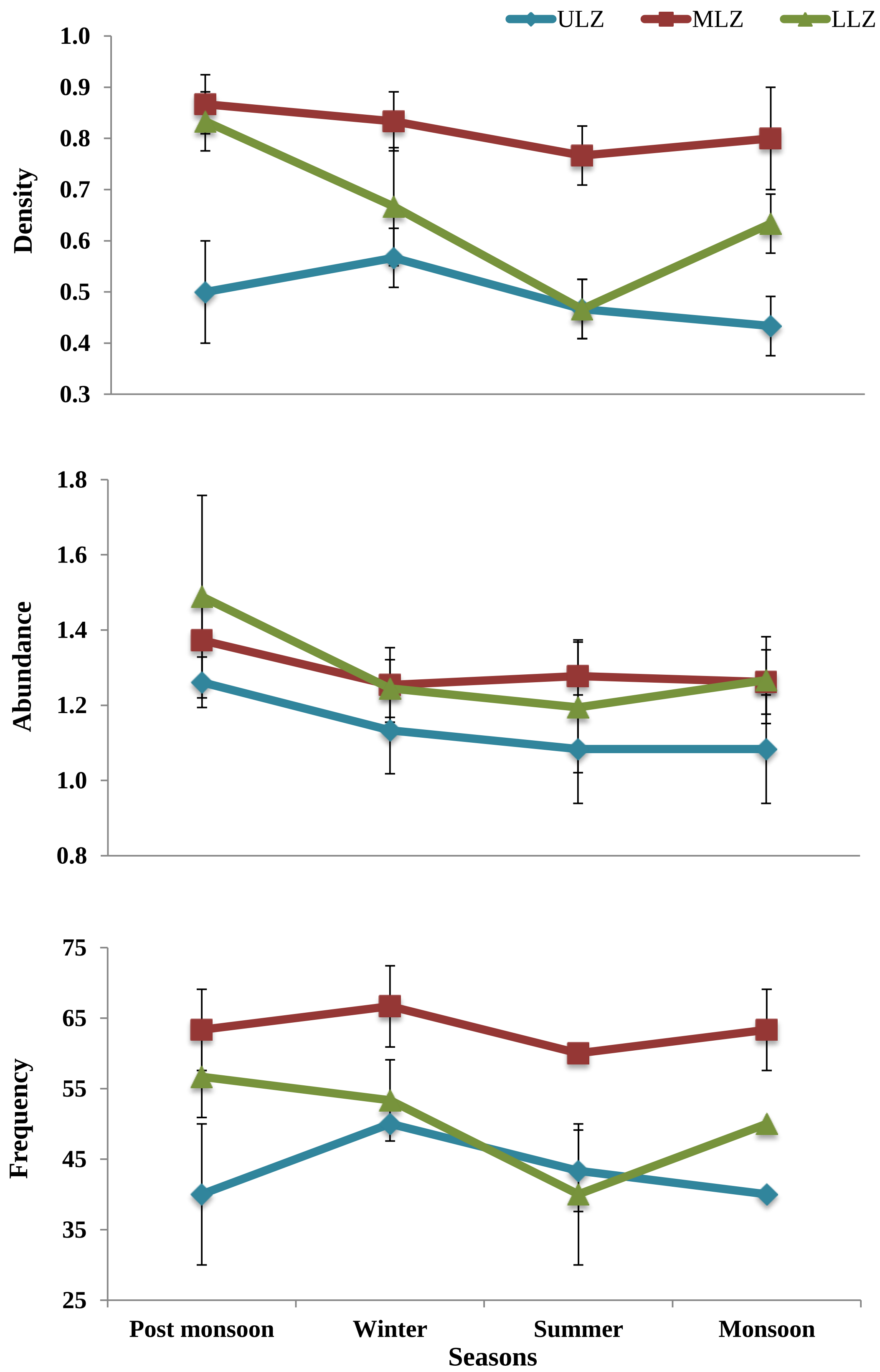

Figure 27. Seasonal variations in various ecological attributes values (0.25 m^{-2}) of *Turbo intercostalis* in different littoral zones at sampling site Veraval.

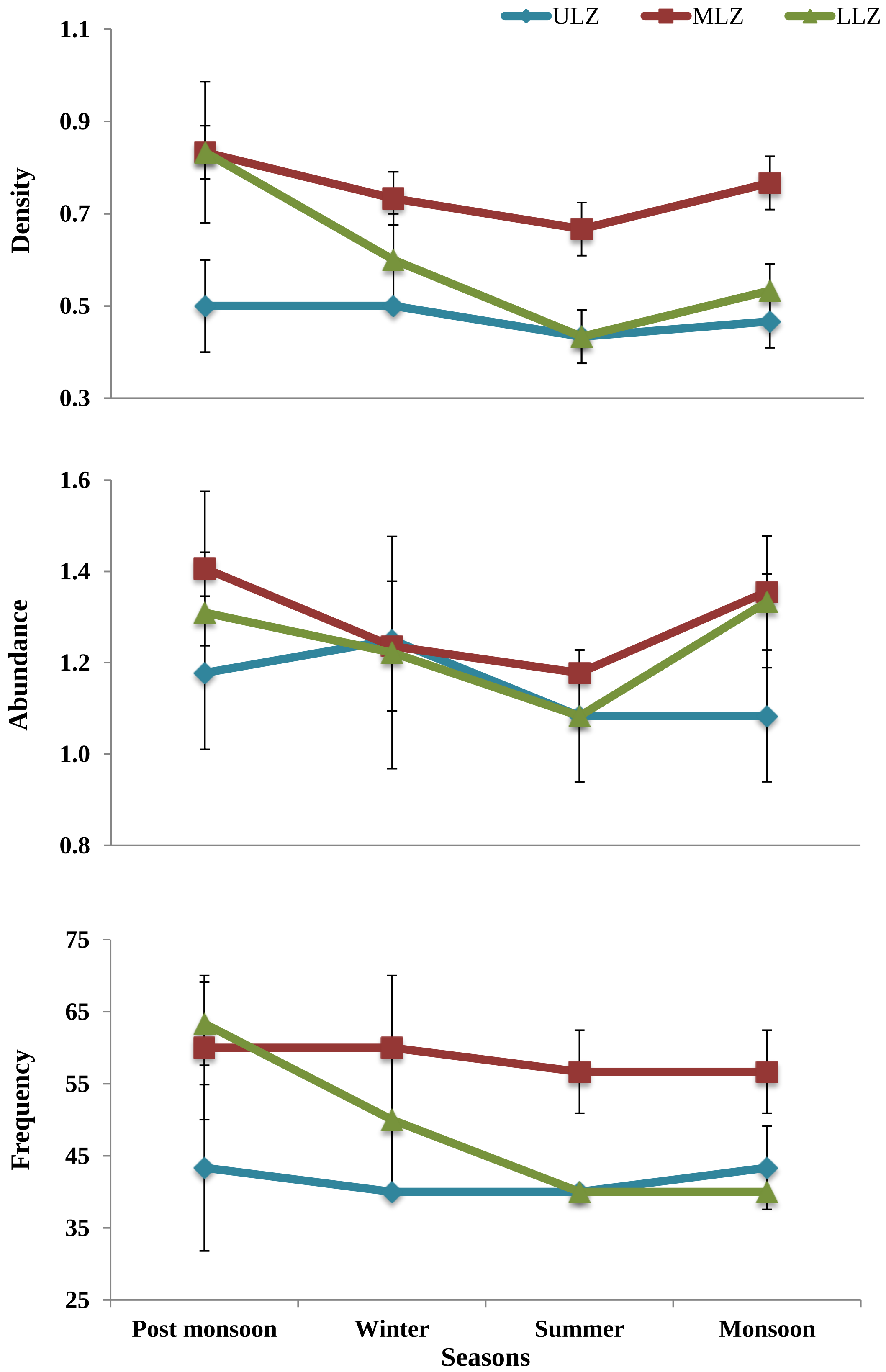

Figure 28. Seasonal variations in various ecological attributes values (0.25 m^{-2}) of *Turbo intercostalis* in different littoral zones at sampling station Kodinar.

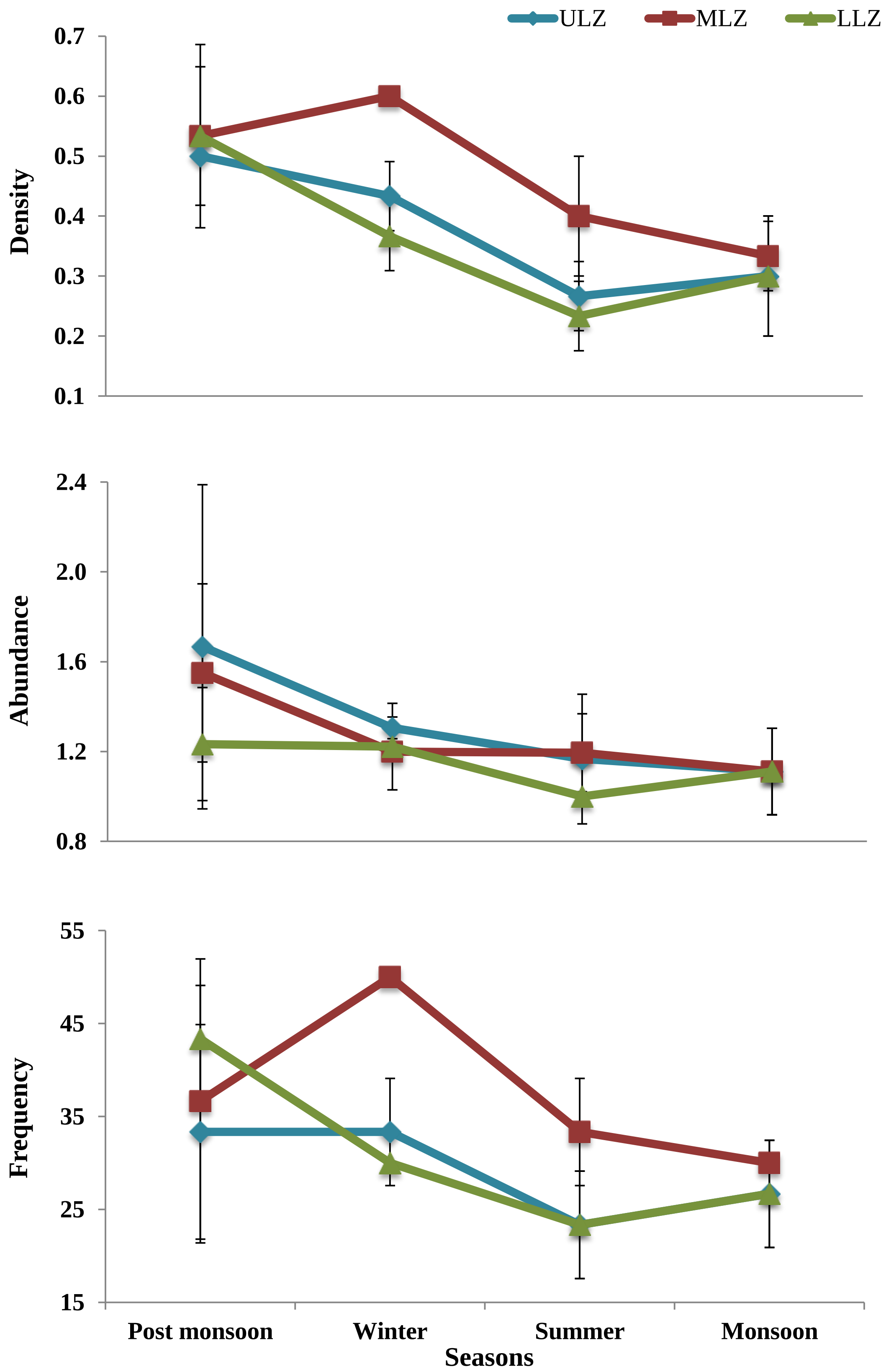

Figure 29. Seasonal variations in various ecological attributes values (0.25 m^{-2}) of *Nerita albicilla* in different littoral zones at sampling site Dwarka.

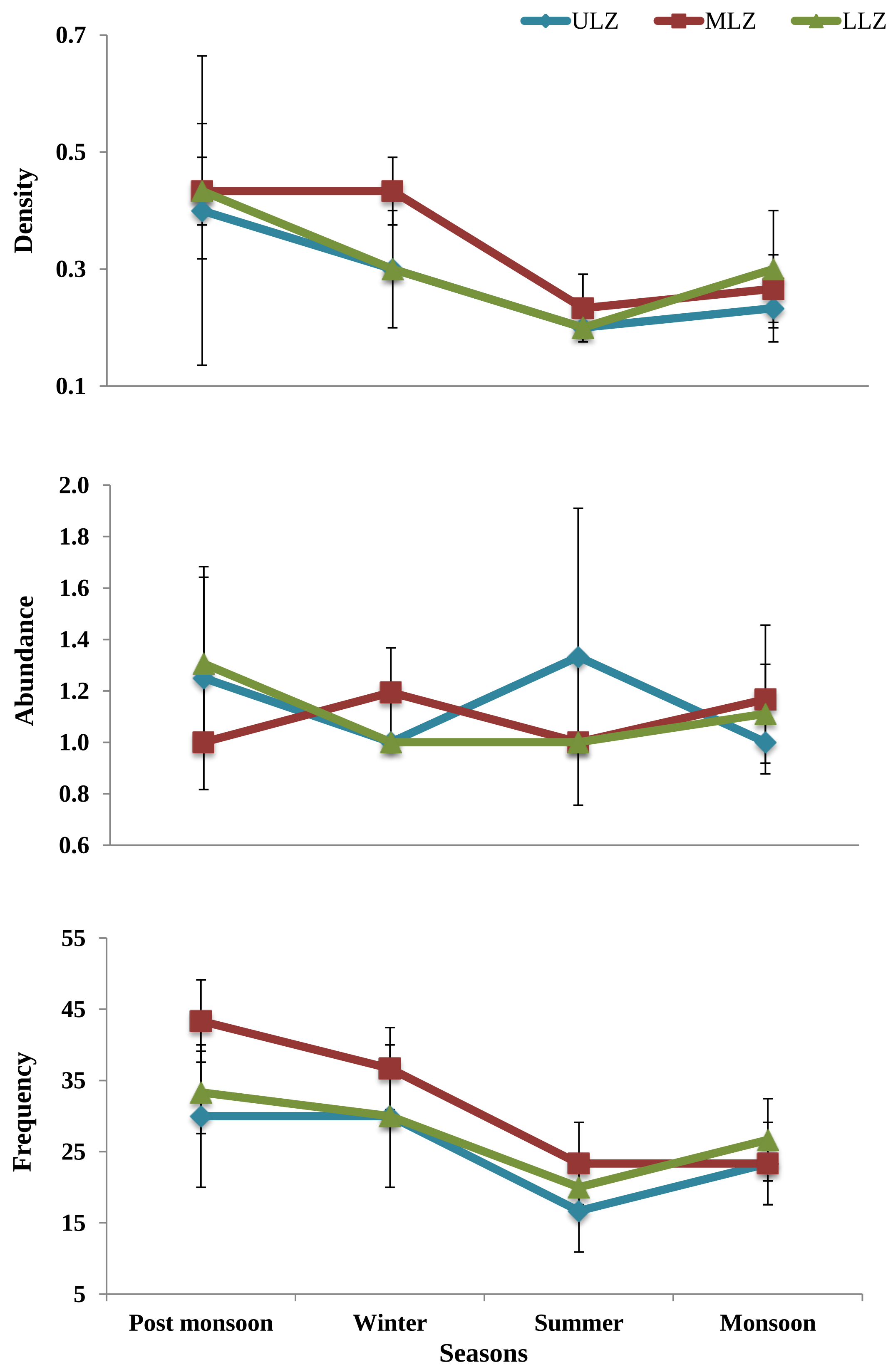

Figure 30. Seasonal variations in various ecological attributes values (0.25 m^{-2}) of *Nerita albicilla* in different littoral zones at sampling site Mangrol.

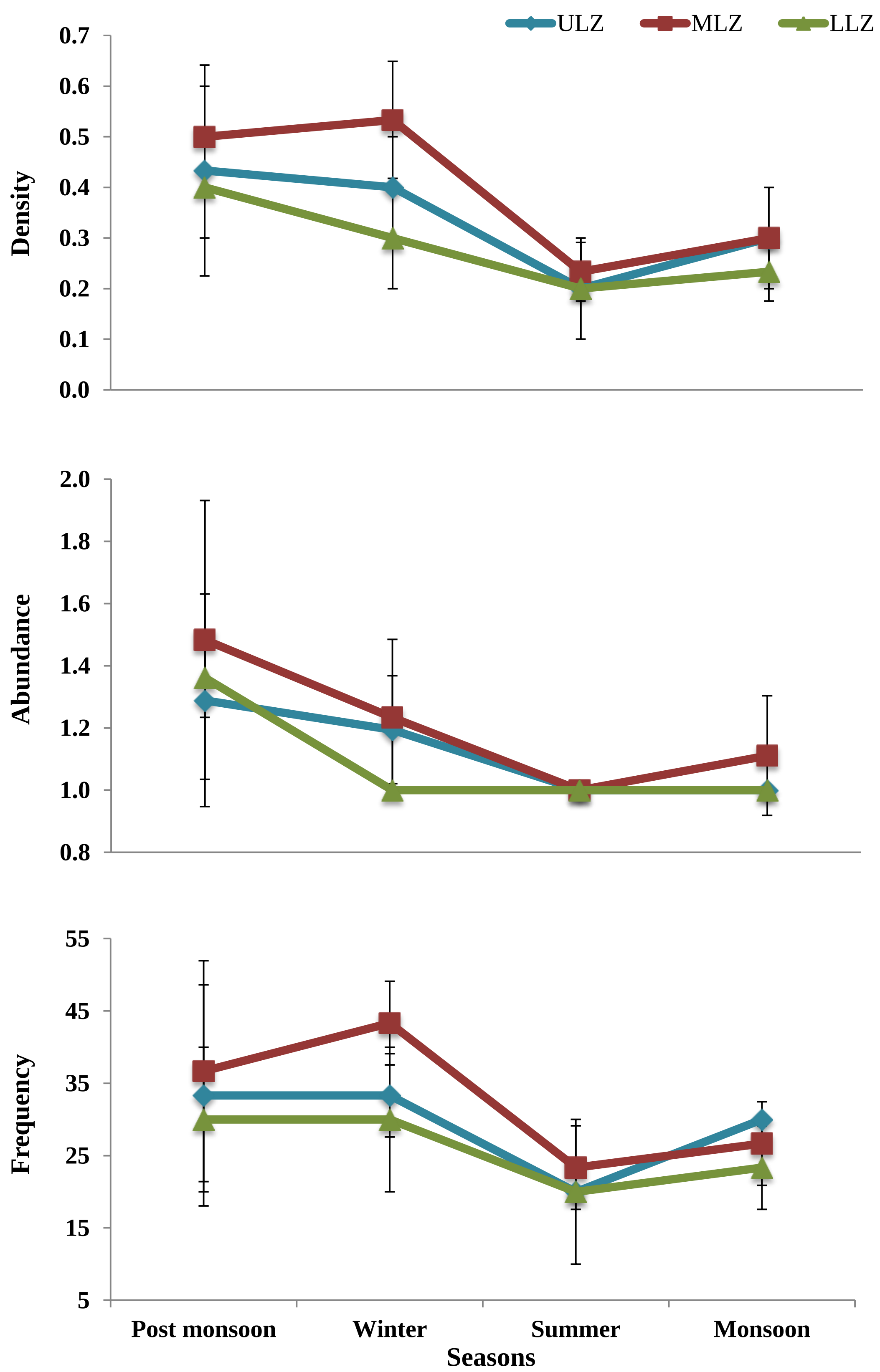

Figure 31. Seasonal variations in various ecological attributes values (0.25 m^{-2}) of *Nerita albicilla* in different littoral zones at sampling site Veraval.

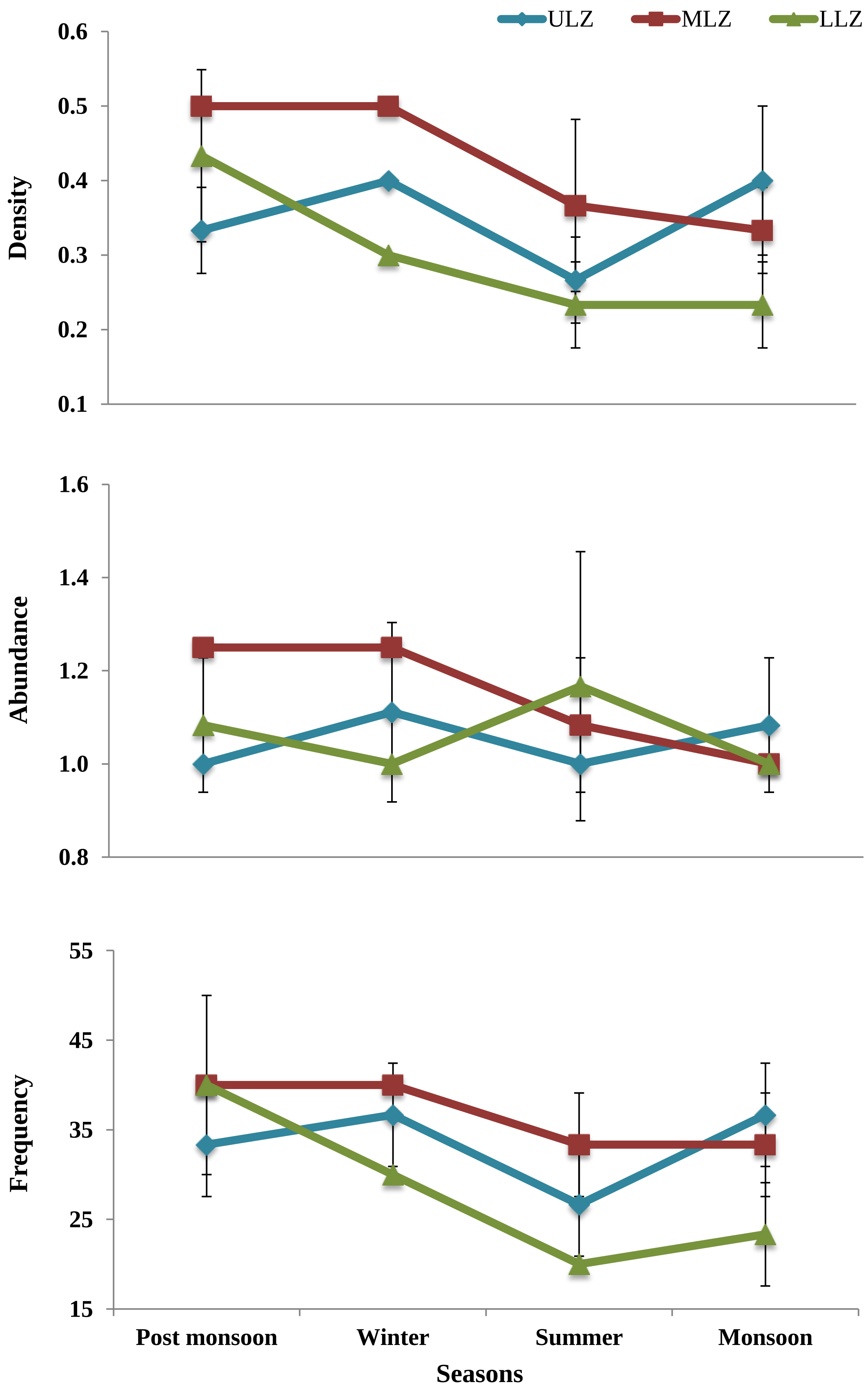

Figure 32. Seasonal variations in various ecological attributes values (0.25 m^{-2}) of *Nerita albicilla* in different littoral zones at sampling site Kodinar.

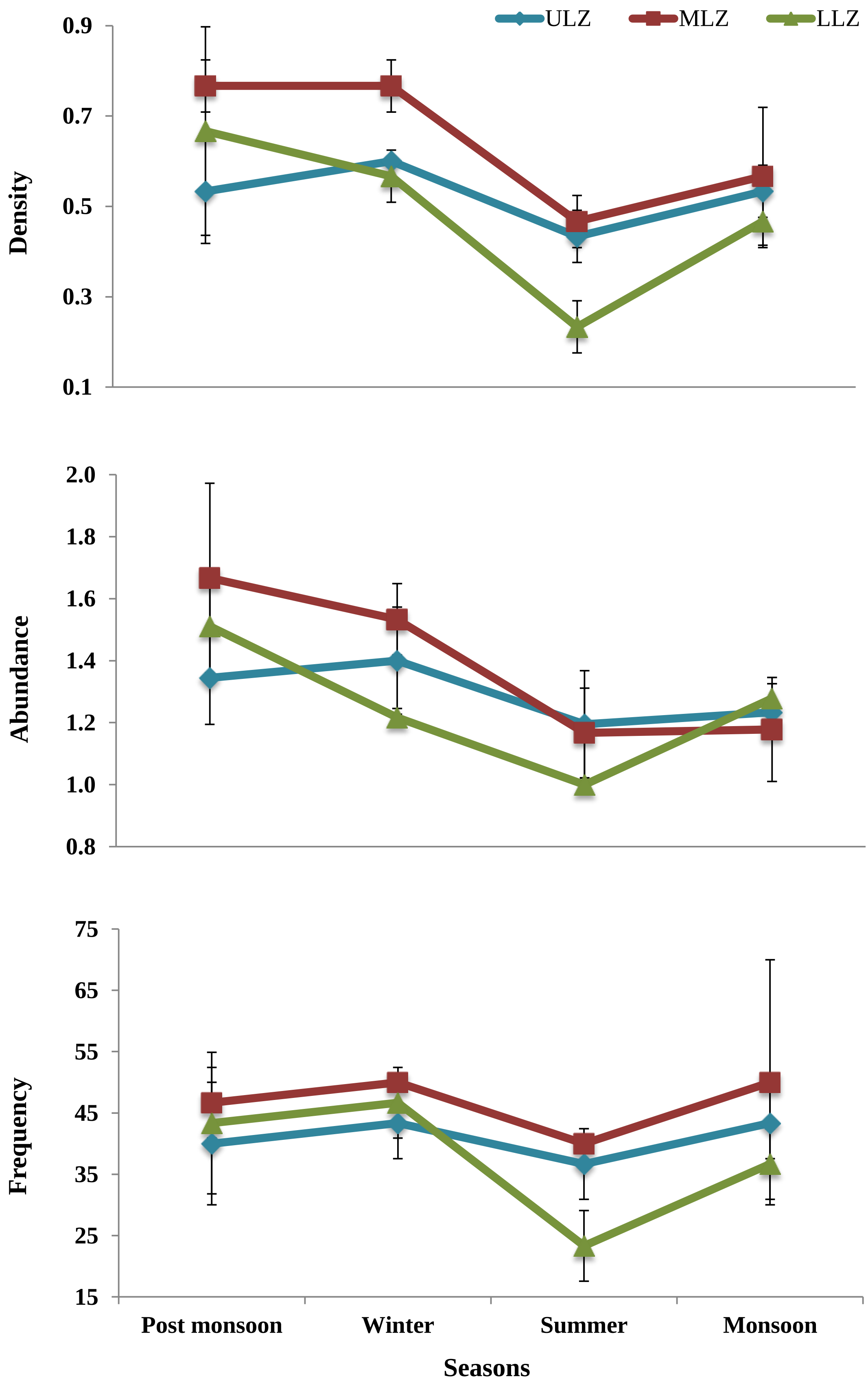

Figure 33. Seasonal variations in various ecological attributes values (0.25 m^{-2}) of *Rhinoclavis sinensis* in different littoral zones at sampling site Dwarka.

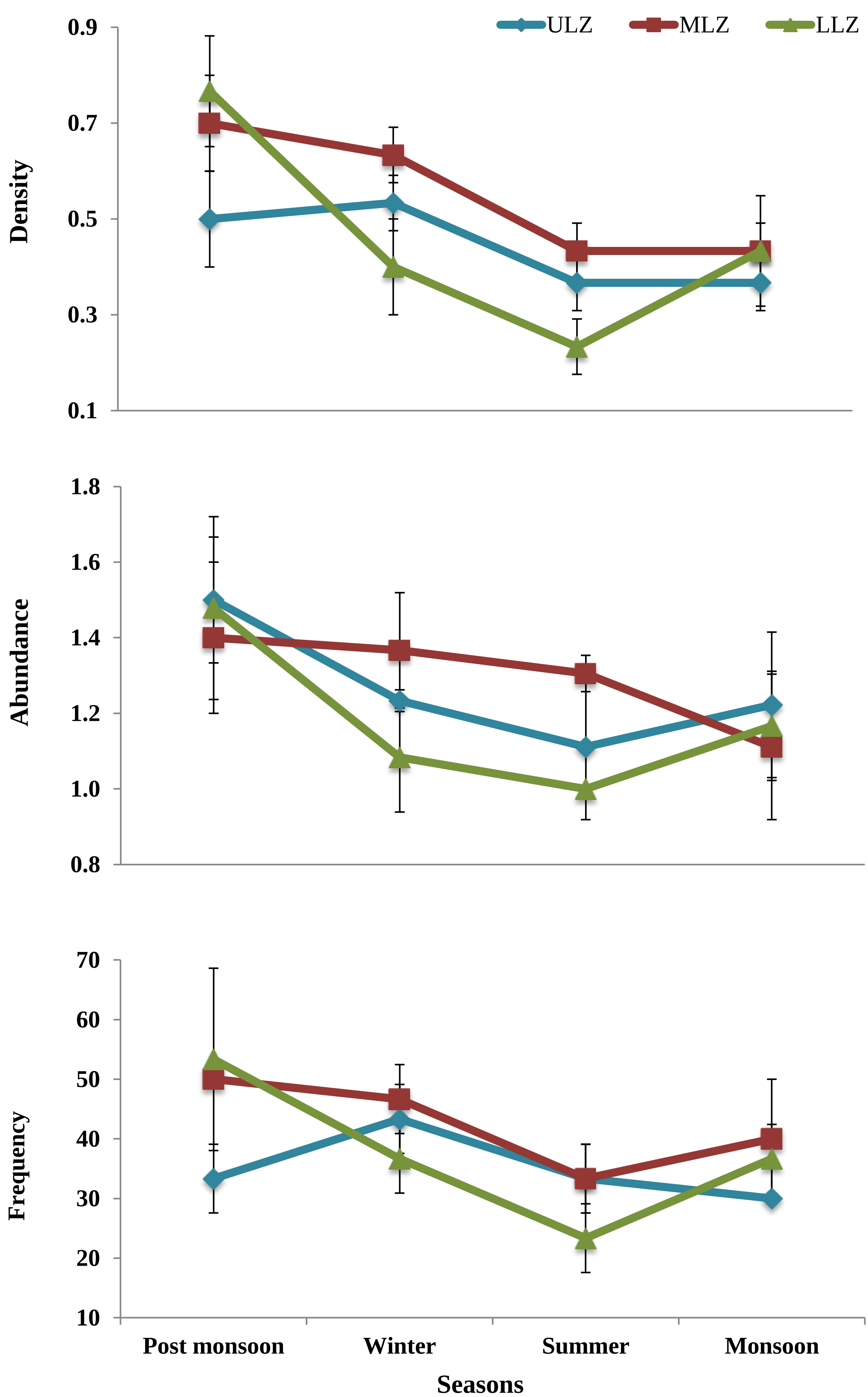

Figure 34. Seasonal variations in various ecological attributes values (0.25 m^{-2}) of *Rhinoclavis sinensis* in different littoral zones at sampling site Mangrol.

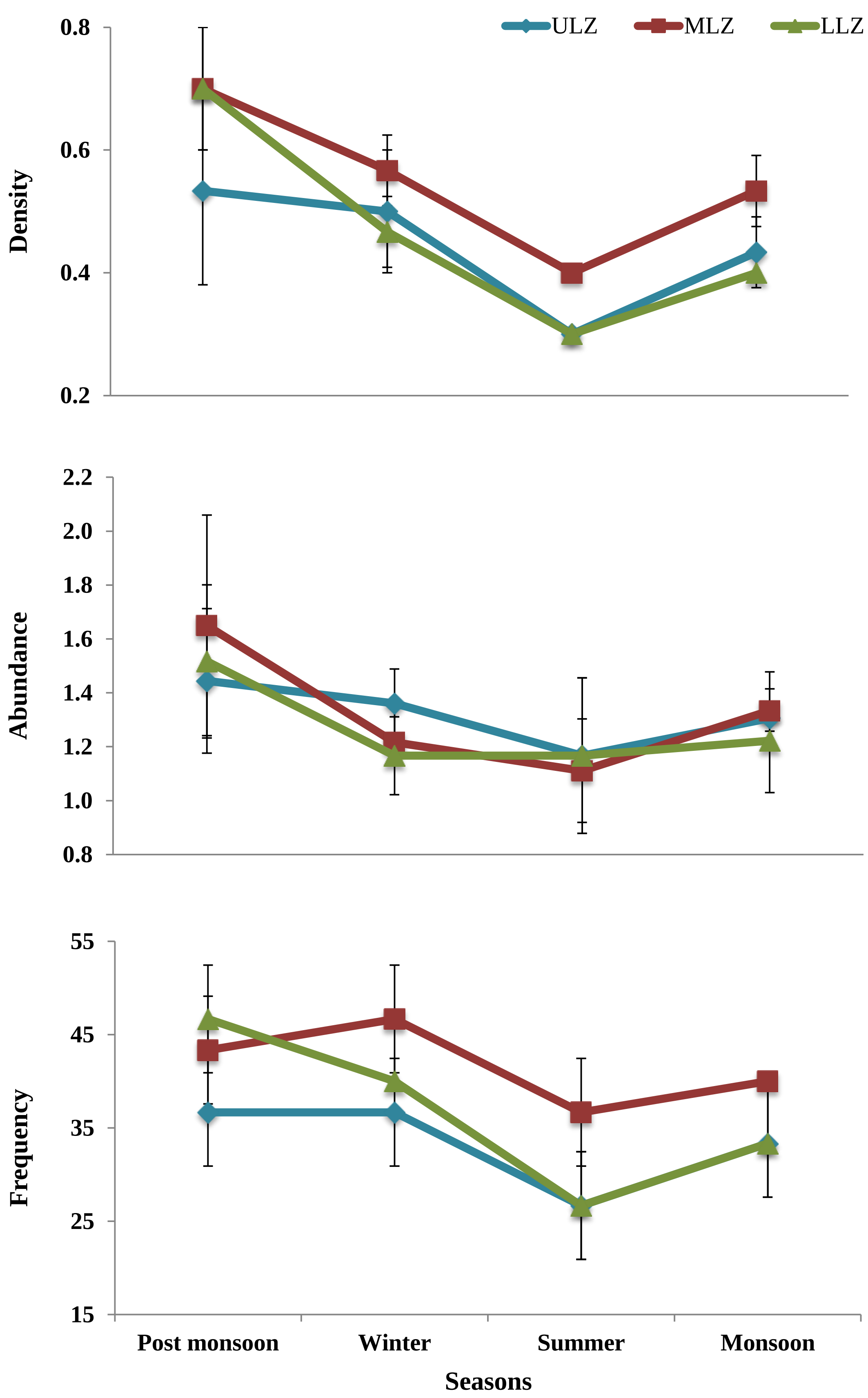

Figure 35. Seasonal variations in various ecological attributes values (0.25 m^{-2}) of *Rhinoclavis sinensis* in different littoral zones at sampling site Veraval.

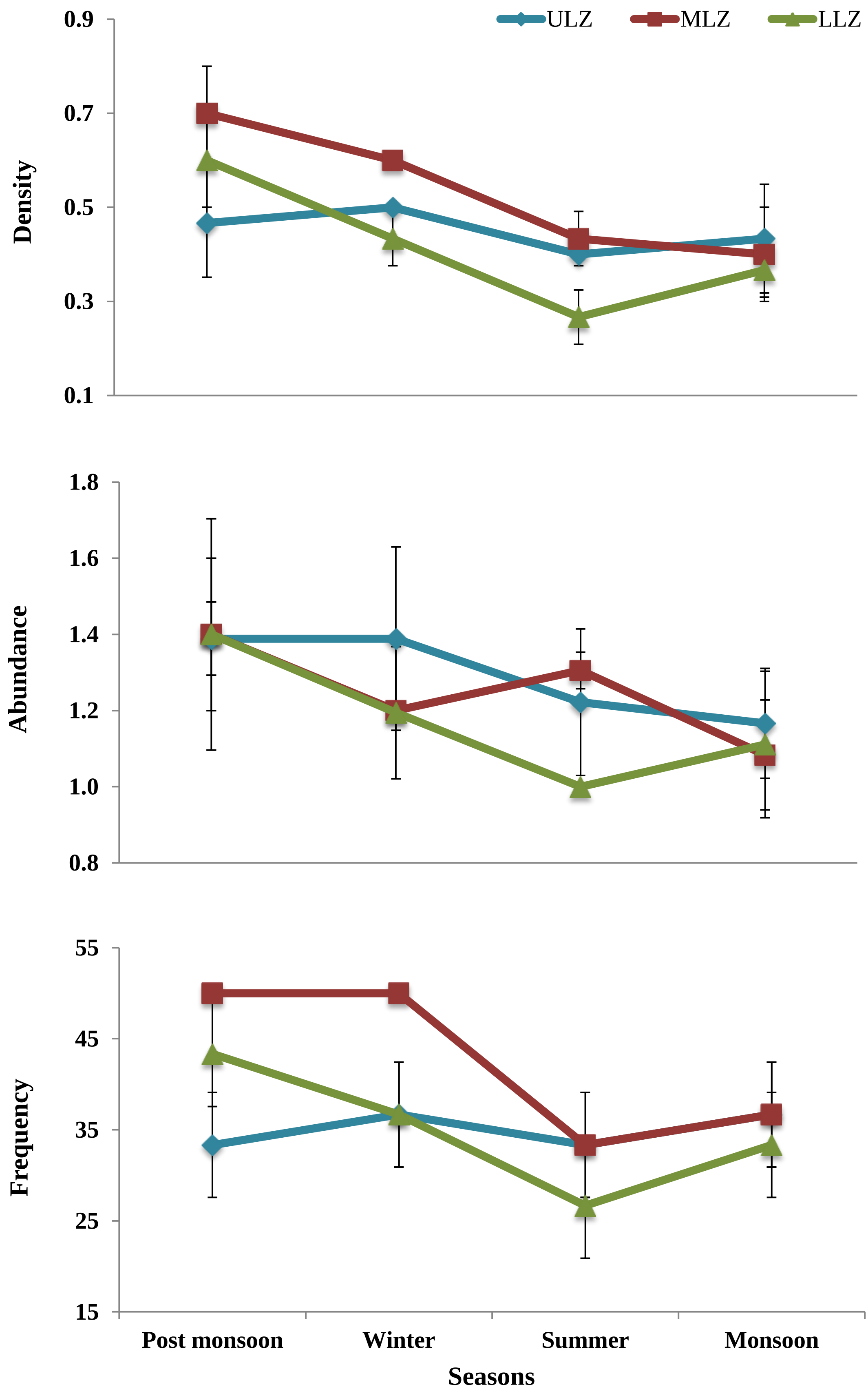

Figure 36. Seasonal variations in various ecological attributes values (0.25 m^{-2}) of *Rhinoclavis sinensis* in different littoral zones at sampling site Kodinar.

4.8. Heavy Metal in Sea water

The distribution of metals, Pb (Lead), Zn (Zinc), Cd (Cadmium) and Cu (Copper) concentrations in the study area is presented in Figure 37 to 40. The Pb (Lead) in coastal water fluctuated between 0.095 mg/l at sampling site Dwarka during Monsoon and 0.224 mg/l at sampling site Kodinar during winter, while the concentration at Veraval coastal zone ranged from 0.140 mg/l during post-monsoon to 0.194 mg/l during winter. However, at the sampling site Mangrol the concentration level of Pb showed variability in the sea water samples from 0.120 mg/l to 0.185 mg/l. Generally, the range showed elevated levels of lead content in the sea water samples from study area (Figure 37).

The variation of zinc concentration in the sea water ranged between 0.230 mg/l at Dwarka during winter and 0.625 mg/l at Veraval during post-monsoon. The concentration of zinc showed less values at Dwarka compared to other sites, while during monsoon season zinc concentration was slightly low at Mangrol than that of the sampling site Dwarka (Figure 38). There was no much difference observed in case of zinc concentration at sea water samples from Mangrol during various seasons, the concentration ranged from 0.300 mg/l during monsoon to 0.370 mg/l during summer. The zinc concentration in sea water was much higher at Veraval and Kodinar than the other sites throughout the study period.

The high levels of cadmium concentration in seawater recorded at Kodinar (0.112 mg/l) and Veraval (0.108 mg/l) during winter and summer season respectively. There was a tendency towards decreasing cadmium concentration in sea water samples at site Mangrol and Kodinar during monsoon to post-monsoon season. It was observed that the concentration of cadmium was much lower at Dwarka (0.066 mg/l) and Veraval (0.068 mg/l) during monsoon season (Figure 39).

The seasonal variability revealed elevated values in monsoon and winter period in case of copper concentration in sea water samples from study area. The variations in copper in the investigated area were illustrated in figure 3. In the sampling site Veraval, the values of copper content fluctuated between 0.498 mg/l during monsoon and 0.690 mg/l during winter season. In the sea water samples from Mangrol, the values ranged from 0.482 mg/l during post-monsoon to 0.560 mg/l during monsoon throughout the study period. The concentration of copper varied from 0.426 mg/l to 0.686 mg/l at Kodinar during the entire study period (Figure 40). The values of copper concentration showed a clear trend increased from summer to monsoon at Kodinar. The results of various heavy metals in seawater samples showed more or less seasonal variations throughout the study period at those of sampling sites.

In the present study the correlation matrix for the different trace metals content in seawater samples collected from different sampling sites showed that there were no significant correlations for some pairs of trace metals (Table 4). The correlation of cadmium and copper concentration with lead was poor r = 0.222 and 0.217 at the seawater samples from Dwarka and Kodinar sampling sites respectively. On the other hand, superior positive correlation (r = 0.869) was found between cadmium and lead content in seawater sample collected from Mangrol. The negative correlation found in case of zinc and copper concentration in seawater (r = - 0.695) at Veraval sampling site. The relationship between cadmium and lead with zinc showed negative correlations (r = - 0.644, −0.608 respectively) at the sampling site Veraval. Most of the negative relationships were found between cadmium and zinc (r = - 0.436) at Dwarka, copper and lead (- 0.787), zinc and copper (- 0.382) at sampling site Kodinar. There was a positive correlation between copper and cadmium at all the sampling site (Table 4).

Table 4. Inter-relation between various heavy metal concentrations at four selected sampling sites of Saurashtra coastline.

	Dwarka	Mangrol	Veraval	Kodinar
Lead × Zinc	-0.293	-0.429	-0.608	-0.244
Cadmium × Lead	0.222	0.869	-0.146	-0.047
Copper × Lead	0.542	0.519	0.330	-0.787
Zinc × Copper	-0.037	-0.006	-0.695	-0.382
Copper × Cadmium	0.814	0.724	0.778	0.217
Cadmium × Zinc	-0.436	0.036	-0.644	-0.007

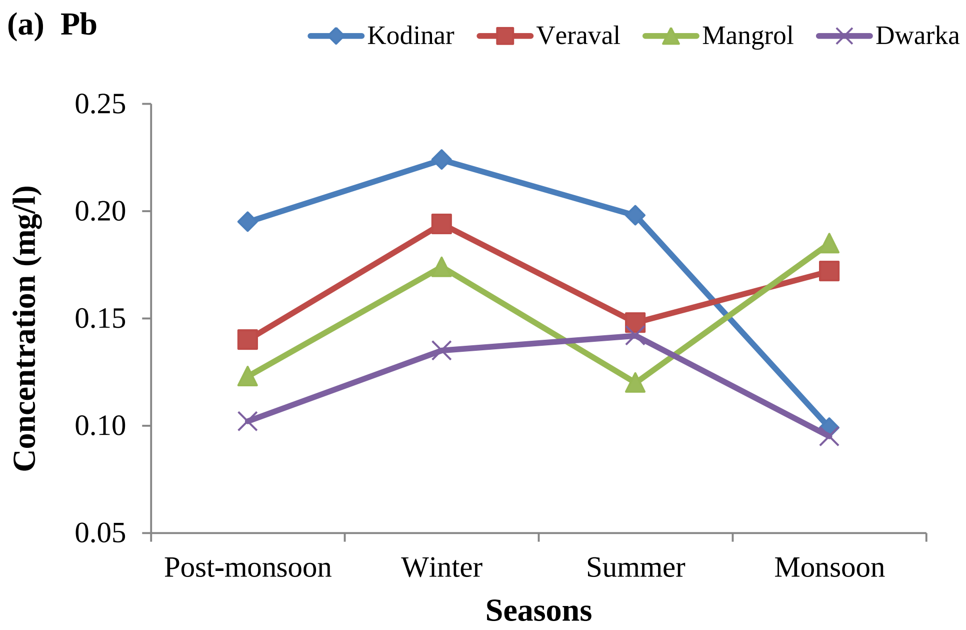

Figure 37. Lead concentration in seawater during various seasons at different sampling sites of Saurashtra coastline.

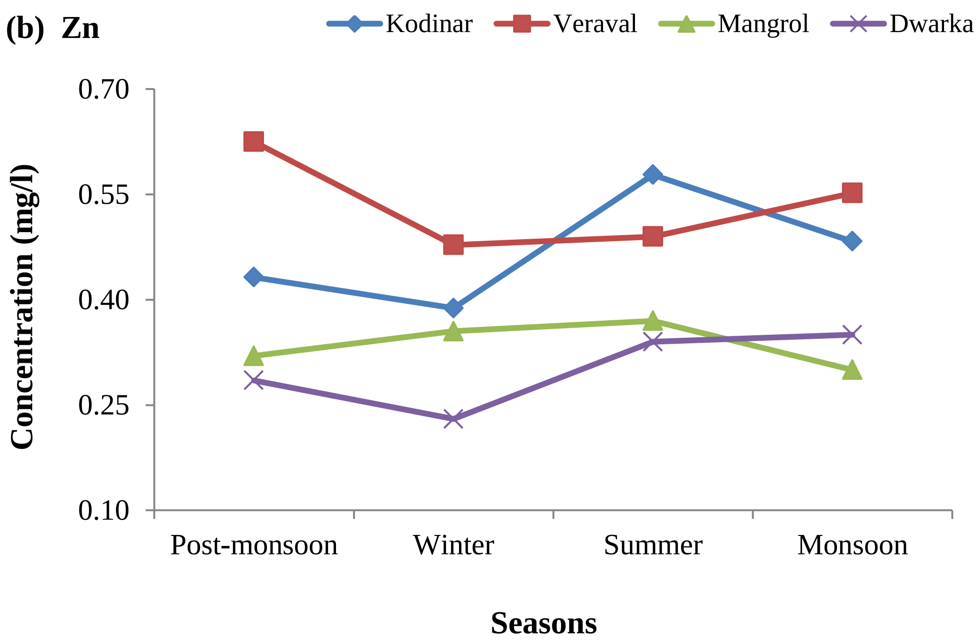

Figure 38. Zinc concentration in seawater during various seasons at different sampling sites of Saurashtra coastline.

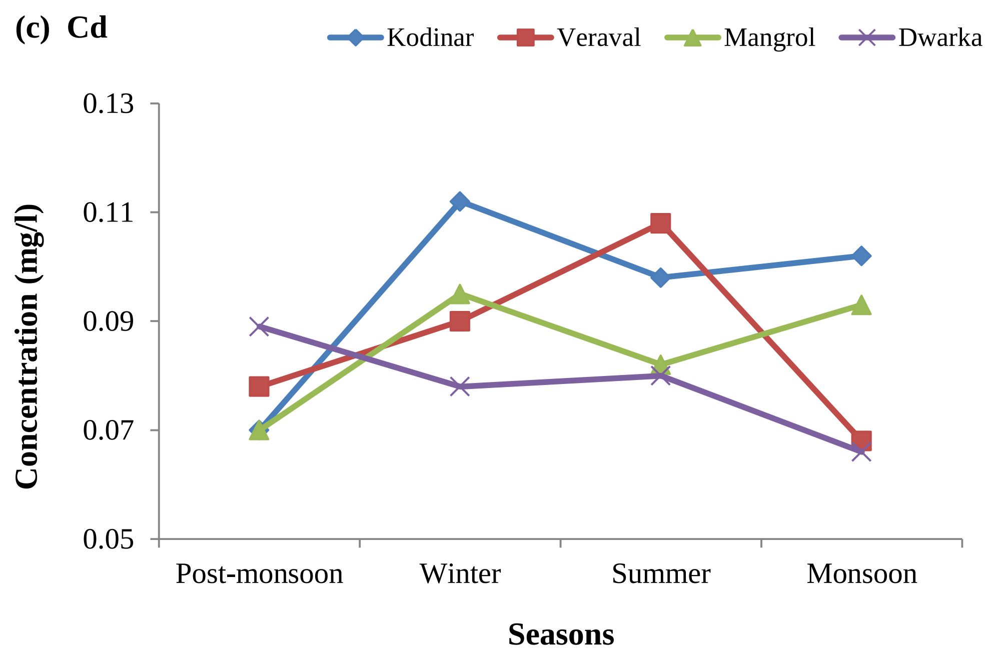

Figure 39. Cadmium concentration in seawater during various seasons at different sampling sites of Saurashtra coastline.

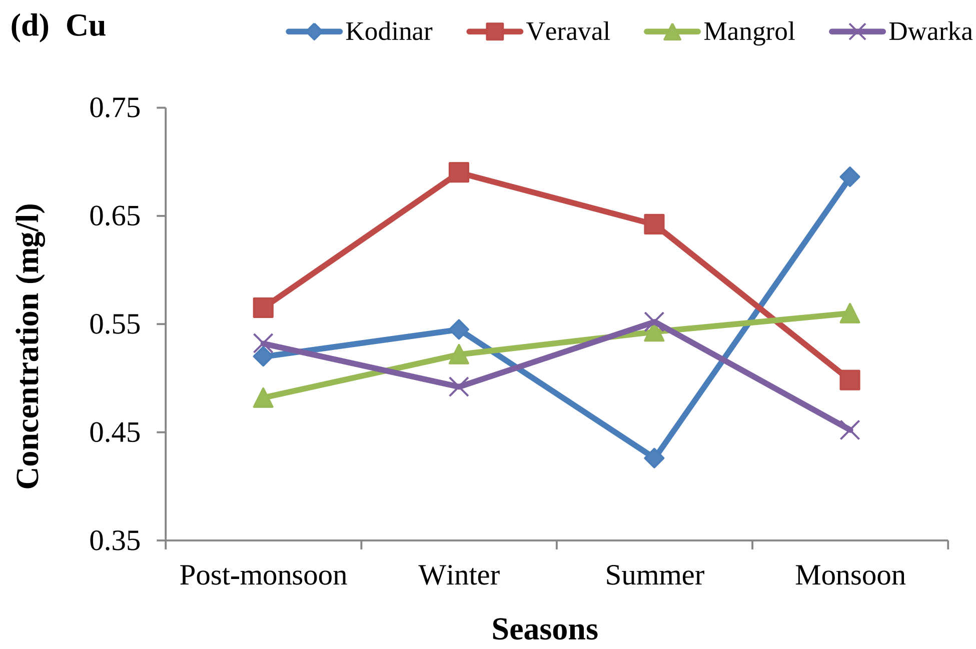

Figure 40. Cadmium Concentration in seawater during various seasons at different sampling sites of Saurashtra Coastline.

Chapter - V: Discussion

5.1. General Discussion

India has a vast extent of coast line of about 8000 km straddling 13 maritime mainland states and Union Territories, which are address to a diversity of coastal and marine ecosystems, comprising nationally and globally significant. The sea around India is part of the great Indian Ocean and the Indian subcontinent forms a major physical division between the Arabian Sea and the Bay of Bengal of the Indian Ocean. Coral reefs are diverse and most vulnerable ecosystem in India; is quite significant and includes 180 species of benthic algae, 14 species of seaweeds, 12 species of sea grasses, 108 species of sponges, 4 species of lobsters, 103 species of echinoderms, 600 species of fin fishes and also a good number of species of crabs, bivalves, gastropods and cephalopods each in Lakshadweep and Andaman and Nicobar islands (Devaraj, 1997). In India, 208 species of hard corals and About 844 species of marine algae have been described by Venkataraman (2003). Although extensive marine algal collections have been made since the eighteenth century from Indian Ocean region, Iyengar (1927) was the first phycologist to publish the marine algal flora of the Indian coast. “A Checklist of Indian Marine Algae” listing 520 species from the Indian coast including 153 species for Gujarat. This checklist was further updated by Untawale et al. (1983), Sahoo et al. (2001) and Oza and Zaidi (2001) and reported 620 species, 770 species and 844 species, respectively.

The present investigation was intended to study the human interaction and its effect on natural system. The existing study deals with the macrofaunal and seaweed diversity on the intertidal area of the Saurashtra coast. Spatial as well as temporal variation in population ecology of few prominent molluscan species was studied at four different locations along with that various anthropogenic activities and its effects on the coastal area was also observed. With a view to assess the status of intertidal macrofauna, heavy metal pollution in seawater and the interaction between the fauna and anthropogenic activities were investigated. The western coastal area of India, these days is considerably being exploited heavy by various kinds of industries. This study revealed how this is affecting the ecosystem of this area.

5.2. Zonation

One easily visible feature of intertidal communities is vertical zonation, where the community is divided into distinct vertical bands of specific species going up the shore. Conditions on the intertidal zone change, becoming wetter or drier, more or less exposed, more or less steeply sloped etc. as one moves around. These changes influence the composition, abundance and distribution of the population (Lewis, 1972).
Intertidal organisms are subject to a vertical gradient of increasing stress with increasing exposure to air higher on the shore (Crowe et al., 2000). This leads to increased abundance within zones where conditions are favorable to species survival. Thus, abundance decreases outside of this zone as the physical environment becomes less suitable. Species ability to cope with desiccation determines their upper limits, while competition with other species sets their lower limits. In 1949 the ecologists Stephenson and Stephenson devised a classification scheme of zonation of all Rocky Shores, based upon Lewis' extensive zonation studies of British Rocky Coasts (Lewis, 1972). Both Stephenson's and Lewis' schemes are based upon the position of key communities along a vertical gradient of the shore. Tidal heights are ignored thus, allowing ecologists to perform fieldwork simply and effectively.

The rocky intertidal region can be divided into four vertical zones. These zones are based on height and tidal influence. These four zones include from the highest to the lowest: the splash zone, the high intertidal zone, the mid-intertidal zone, and the low intertidal zone. Ecologically, the intertidal zone is a diverse community where organisms are divided by the vertical zonation of the tidal zones.

This supralittoral (spray zone) zone is above the highest high tide mark. It is moistened by saltwater spray from waves and freshwater runoff by rain and streams. This relatively dry area is sparsely populated. Few organisms can withstand the extreme fluctuations in moisture, temperature, and salinity found in this zone. The spray zone is never submerged and only receives ocean water due to the splash from crashing waves.

The Upper intertidal zone, usually termed the lottorina zone, named after the small herbivorous gastropods (periwinkles) that occupy this zone that must survive long periods of exposure. This zone extends higher than the highest tide where there is great exposure with spray from the various waves causing the organisms to extend higher into the littoral zone. Parts of this region are exposed to the air for long periods as the tides recede. The inhabitants of this area are sturdy individuals. They can remain wet even if they are exposed to the sun and wind.

The midlittoral zone, a broader zone dominated by barnacles and mussels. The middle tide zone is regularly both exposed and submerged by the tide. The middle intertidal zone can accommodate more life than the upper intertidal zone due to its length of time that it is submerged in water. The organisms worry less about desiccation. The organisms in this zone vary, but in greater quantity.

The low littoral zone dominated by red algae, often with brown seaweeds. The low tide zone is mostly submerged and only exposed to the air during the lowest tides. The lower intertidal zone is mostly submerged underwater most of the time and is only exposed when it is low tide. The lower intertidal zone is more rich in organisms, more so than the middle intertidal zone. There is more species richness in the lower intertidal because most of the time the organisms are submerged in water, so more interaction takes place.

5.3. Macrofaunal Diversity

The intertidal macro-invertebrates showed fluctuations among different sampling sites of Saurashtra coast. There has been a renaissance of taxonomy and related subjects such as abundance and distribution of species as biodiversity in the last two decades. This has resulted from growing awareness that ecological, economic and livelihood securities of mankind are inseparably linked with the maintenance of the diversity of the biological components in land, water and atmospheric environments. For the variety of reasons, macrofauna are extremely important in the functioning of coastal system, from a logistic standpoint that they make a good study specimen, because they are abundant, readily surveyed and taxonomically rich.

Macrofaunal groups like coelenterata (Patel, 1978, 1988; Pillai and Patel, 1988; Deshmukhe, et al., 2000) and mollusca (Misra and Kundu, 2005; Vaghela et al., 2010) were studied along the Saurashtra coast. Raghunathan et al. (2004) examined that the gastropod group were the dominant comprising about 27 species followed by crab which comprises 8 species at Veraval. In the present study, amongst four sites, Dwarka showed more macrofaunal diversity on the intertidal belt than the other sites. Mollusca were the most dominant group and platyhelminthes was the least observed group. A clear dominance was observed between the sampling site of Veraval and Kodinar based on the macrofaunal diversity. In the present investigation, a total of 120 species were recorded from the four sampling sites in Saurashtra peninsula.

It was observed during the present study that in the case of macrofauna, the sponge population was less because sponge is very delicate and damaged by fishermen and other people. They were seen mainly in middle and lower littoral zone, somewhat present in upper littoral but not in dried area. Among the various intertidal faunal groups, porifera has an evolutionary history of about 570 million years and so far, 486 species have been described in India (Thomas, 1998). The Gulf of Kachchh has the highest diversity about 25 species of sponges (Venkataraman and Wafar, 2005).

It has been found in group coelenterata that the variation in species was high in lower littoral zone and minimum was in upper littoral zone. This may be due to the fact that lower littoral zone was least exposed zone and upper littoral zone was the maximum exposed one, providing the habitat for only some selected species of this sessile group.
Among the corals from the intertidal region three species (*Goniastraea pectinata, Hydnophora exesa* and *Montipora folisa*) were recorded from all the sampling sites. However, all these coral species have a patchy distribution along the rocky intertidal coast (Raghunathan, et al., 2004). The occurrence of the corals in the intertidal zone is restricted between middle littoral and lower littoral zones. Species like *Portis lutea* and *Favia favulus* were recorded mostly in rock pools. The *Zoanthus* population is quite good here. In the pools of rocky beach, sea anemones were found. However, the lower zone consists of big boulders usually covered with *Zoanthus*.

Platyhelminthes group comprised three species, which was present in tide pools with the existence of water during low tide and associated with algae. In case of annelida, *Nereis pelagica* and *Heteronereis sp.* was present in sandy portion and under the rock in pools and due to its nature of burrowing, rarely came out in the open. *Chetopterus chetopterus, Serpula vermicularis* and *Sabella pavonica* were mostly found in lower littoral zone and attached with rocks. The arthropoda group is prefers to be in association with intertidal algae at upper and middle littoral zone, especially in the pools and puddles. Arthropoda feeds on the algae as well as zooplankton, thus, vigorous tidal activity of the lower littoral zone might not be a suitable place for them.

Group Mollusca showed more or less similar trend in upper and middle littoral zones. This trend may be due to the fact that the mollusca mainly feed on the marine algae and thus, always associated with intertidal seaweeds. The intertidal areas with rocky and partly sand substrate provide the habitat preferred by the molluscs under study. Mollusca have been recorded 3379 species along the Indian coast from the marine habitat (Subba Rao, 2003). Among that eight species of oysters, two species of mussels, 17 species of clams, six species of pearl oysters, four species of giant clams and other gastropods such as *Trochus*, *Turbo* as well as 15 species of cephalopods are exploited from the Indian marine region (Venkataraman and Wafar, 2005).

Particularly echinoderms were commonly observed hidden in crevices, small caves and between algal cover. Similarly, the gastropods were found abundant and frequently, associate with seaweeds and the important role of seaweeds as refuge and substrate for many invertebrates. In the case of echinodermata species number was less because *Asterina gibbosa* and *Ophioderma brevispinum* inhabiting deep water. But also present in intertidal zone. On the whole, it appears that in general, this area rich in macrofauna and algae. *Ophioderma brevispinum* was communally occurred and the distributed species in this group at almost all the sampling sites.

The results of present investigation suggested that higher dominance of intertidal invertebrate species in the middle and lower littoral zone, as compared to the upper littoral, due to organisms of intertidal zone preferred a healthier environment. Misra and Kundu (2005) reported the marine animals along the intertidal have to protect themselves against high salinity, desiccation and against the predators. This is achieved through taking shelter under the thick cover of the seaweeds which grow better on the middle and lower littoral zone. Seaweeds on the upper littoral zone get desiccated out during the period of emergence, and therefore the animals cannot get shelter much at upper littoral zone. Therefore, with the advent of the disappearances of seaweed along the upper and middle littoral, the animal migrates towards the lower littoral as a safer

habitat (Misra, 2004; Ramoliya, et al., 2007; Vaghela, et al., 2010). The lower littoral zone of the entire Saurashtra coastline is quite different in nature from other coasts. The rough edge of the lower littoral zone creates very strong wave force, thus, generating strong tearing force. That's hampers the settlement of the algae and feeble footed molluscs. However, the zone seemed to be the best suited one for intertidal organisms.
The intertidal harbours many microhabitats like tide pools, small puddles, crevices, and small channels. Thus, the spore lings of seaweeds germinate, settle and grow at a particular microhabitat. However, all the earlier finding and the present study confirms one important point and that is, maximum seaweed growth occurs during the winter months of December and January when the seawater temperature shows a minimum couple with maximum dissolved oxygen content (Patel, 2002; Vaghela, et al., 2010).

It is clear that there was greater degree of similarity between the middle and lower littoral levels of the intertidal than upper and middle littoral levels with respect to their biota. During the period of emergence i.e., at low tides, the first part to get emerged is the upper littoral zone and the last emerged is the lower littoral zone. This results in a maximum exposure time of the upper littoral and minimum exposure time of the lower littoral. Different organisms adapted to these environments take shelter at a suitable tidal level. So far as the seaweeds are concerned, these inhabiting the upper littoral get dried out and die first. On the contrary, organisms inhabiting the lower littoral level are the least exposed to the ambient environment and they get here more stable habitat as compared to the upper and middle littoral levels.

Intertidal macrofaunal community is characterized by temporal and spatial changes in the population and the vertical zonation is the most obvious distribution pattern of hard substrate communities (Witman and Dayton, 2001). The macrofaunal invertebrate were found to have a linkage with vegetation through food web (Bell, 1979). The flora and fauna present on intertidal rock platforms currently show relatively little variation between locations, with seasonal fluctuations.

Seasonal variations were moderately erratic at selected locations, maximum macrofaunal occurrence during winter and post-monsoon. In these four sites, among all the invertebrate macrofaunal groups, mollusca constituted highest number of species and seasonal occurrence. While most of the groups exhibited obviously discontinuous seasonal occurrence. Certain macrofauna groups like platyhelminthes and echinodermata were appeared only once or twice during the study.

Marine algae from Indian coasts have been fairly well surveyed since decades. Oza and Zaidi (2001) and Venkataraman and Wafar (2005) listed 844 species distributed among 217 genera. The most abundant among them are Rhodophyta which comprises 4343 species followed by Chlorophyta (216 species) and Phaeophyta which comprises 191 species. Among these, 202 species has been recorded from the Gujarat coast (Venkataraman and Wafar, 2005).

The association of animals on the bases that the algae provided them protection from extreme high and low temperature and their dislodgement by wave action. Further reason for their algal association may be that they also feed on spores, filaments or detritus matter of these algae as evident by their food content (Misra, 2004). From the results of the association of different species of fauna with the flora on the upper littoral zone, it is apparent that *Cellana radiata* seldom associated with *Ulva lactuca, Chiton* with *Ulva lactuca* and *Chaetomorpha antennina.* On the other hand, it appears that the *Trochus radiatus* did not show any specific affinity to any seaweed species. Thus, it is discernible that this species does not have any specific choice with particular algae and may be using the assemblage as source of food (Dudhatra, 2004).

At the middle littoral zone, *Conus miliris* showed affinity with *Ulva lactuca. Nereis* and *Eurythoa complanata* have affinity to association with algae. In this zone *Trochus radiatus* and *Turbo sp.* also present and associated with algae too for feeding and breeding reasons. At the lower littoral zone *Aplysia oculifera* associated with *Sargassum sp.*and *Ulva lactuca.* In general, it appears that, all the animal species were well associated with particularly two seaweed species *Ulva lactuca* and *Sargassum sp.* While, the gastropods *Astgrea stellata and Monodonta australis* associated with almost all species of algae. In general, higher number of species composition and distribution of intertidal macrofauna and algae recorded at all the stations. This could be due to the favorable physico-chemical parameter and hard substratum with many pools and puddles (Subba Rao et al., 2004). In general, it appear that, all the macrofaunal species were well associated with particularly with *Ulva lactuca* and *Sargassum sp.*while, the gastropods associated with almost all species of algae.

5.4. Population Ecology

5.4.1. Mancinella bufo

Mancinella bufo, is generally distinguished from the closely related *Thais* species. It is belonging to the family Muricidae, which is the second largest family in the Neogastropoda with about 600 species recent species (Morris et al., 1980) and they are exclusively marine with a global distribution. *Mancinella bufo* is normally seen associated with green algae in the vertical zones which is a grazer on green algae like chlorophycae as a whole and *Ulva lactuca* in particular (Misra and Kundu, 2005). This species was found to be more prolific in middle and lower littoral zones at all the sampling locations of this coastline. This species did not showed any clear cut spatial variation during seasons. While its abundance was slightly high at the sampling site Mangrol during post-monsoon to summer and somewhat elevated values observed during monsoon at Veraval. The middle and lower littoral zones were preferred by this species and small number of individuals was found in the deep pools and puddles on association with green algae during the low tide (Gohil, 2007). Rock pools provide relatively sheltered microhabitats at all the levels on the shores, and support many organisms such as delicate algae which could not survive on the open shore surface (Vaghela et al., 2010). Thus the presence of rock pools increases the species richness of the shores (Hawkins and Hartnoll, 1983).

The ecological attributes, density abundance and frequency did not show any significant differences between sampling sites. However, the results of ANOVA indicated significant variations at the upper littoral zones between four sampling sites of the ecological attributes like density and frequency values (Table 6, 8). This may be due to the local migration of this highly motile species from upper littoral zones to avoid excessive heat, desiccation and rough tidal activities especially none availability of algal species in the upper littoral zones of each selected sampling sites (Misra and Kundu, 2005). In case of density values at the Mangrol, Veraval and Kodinar showed significant variations between vertical zonal distributions of this species (Table 9), while abundance value showed significant difference at Veraval (Table 10). Results of frequency values did not show significant variation between each littoral zone at the sampling site Dwarka and Veraval (Table 11).

5.4.2. Conus miliaris

Conus miliaris is the gastropod species belonging to family Conidae, which is mostly associated with green algae. It was found from the present study that the intertidal belt of selected locations was generally covered by green and brown algae like *Ulva sp.* and *Sargassum sp.* Therefore, this species migrates from zone to zone for grazing. However the middle and lower littoral zones are most preferable habitat for this species (Underwood, 2000; Misra and Kundu, 2005). Due to this reason the ecological attributes was found to be higher in those prefer littoral zones at each sampling sites. The animal was mostly present in the middle and lower littoral zones. Higher density values observed at each sampling site in the lower littoral zone during post-monsoon season. Ecological attributes of this species showed a clear reduction during the summer seasons. Saurashtra coast is essentially rocky and flat substratum, is a suitable place for this gastropod molluscs (Prasad, 1984; Vaghela et al., 2010). Regarding the species density of this species, showed spatial variation clearly dominated over seasonal variation throughout the sampling period. Similar results were obtained in a study conducted in a tropical region, where variations recorded in density value (Susana et al., 2009). As this group of animals move with the water current, the seasonal variations in tidal height and force played a role in their distribution (Underwood and Chapman, 1998). However the density and abundance values were higher at Mangrol than the other sites because of the intertidal belt of Mangrol sampling site which was mostly covered by green algae, chlorophycae. It was more suitable place for this grazer species. During the summer season ecological attributes were found low at upper littoral followed by lower and middle littoral zone when the atmospheric temperature was high in the upper littoral zone (Vaghela et al., 2010).

The ANOVA test indicates no significant variations in any of the ecological attributes between the three vertical zones and similar in between sampling sites. However, a significant difference of the population frequency was observed between littoral zones at Kodinar (Table 11). This may be due to the flat sloping, gentle wave action on intertidal belt of Kodinar where the vertical zonation is not in existance compared with other sampling sites. At Kodinar, the upper littoral zones is having sandy substratum with rocks and where the growth the algal population is quite low (Vaghela et al., 2010).

5.4.3. Trochus radiatus

The results showed that the ecological attributes were high during each season at sampling site Kodinar. The main reason behind a higher ecological attributes is because the substratum type is somewhat rough and in addition, the intertidal belt have many small sized rock pools which is suitable habitat of this species. One more reason for higher population of this species at that particular area has algal cover over the substratum, which causes its dwellers a better healthy condition. At sampling site Dwarka population of this species was low than the other sites. This may be due to the elevated current and heavy wave action can be exaggerated by pebbles and even large stones being moved around by waves (Shanks and Wright, 1986). The encounter rate increased with the decrease of salinity, bright light and temperature. Apart from the substratum type, these two may be the other controlling factor for this group of animals (Glasby, 1999). There did not observe much seasonal variations at any sampling sites. Apart from the substratum type, salinity and temperature may be the other controlling factor for this group of animals (Glasby, 1999).

Results of the ANOVA showed the significant difference existed between sampling sites in case of density and frequency values (Table 5). However, result showed no significant in abundance value. The comparison of each of the littoral zone at all the sampling sites showed the upper littoral zone of all the sites showed a significant variations in case of population density similarly the middle and lower littoral zones also showed the significant variations throughout the study period (Table 6). While, in population frequency a significant variation observed only in upper and middle littoral zone (Table 9). Intertidal assemblages between shores separated by hundreds of kilometers among sites separated by meters found greater variability at small spatial scales relative to larger scale differences among shores (Underwood and Chapman, 1998; Nakaoka et al., 2006). The statistical analysis showed that, there was no any major difference in abundance values in zonal distribution (Table 10). This may be due to the availability of food was considered to be the most determining factor for this case (Glasby, 1999).

5.4.4. Turbo coronetus

This turbinid species is found mostly on the upper and middle littoral zone of the rocky intertidal substratum and prefer a smooth surface to move on. They occur in the walls of the pools or creeks where water accumulates for a longer duration. Creaks and crevices provide protection from waves and from desiccation, and will increase species richness of a shore and the abundance of the species (Raffaelli and Hughes, 1978). *Turbo coronetus* is covered with a very hard and thick solid shell; fluctuation in physical condition hardly brings any change on their distribution. The distribution of this species was high at Veraval due to such condition to a relatively large extent while the other sampling sites is formed of fragile calcareous stone resembling dead coral base. Thus, it could not offer sufficient smooth and wider open area for individual species. That can be a possible reason for lesser number of this group of animals. Seasonal fluctuation may be due to the change in light duration or the wave of tide (Underwood, 2000).

It was observed from the present investigation that the ecological attributes values followed somewhat same trend at all the sampling locations. The fluctuation was more or less same during winter and post-monsoon. Whereas, the abundance values were showed decline trend at all the sites studied during summer season. The ANOVA test revealed quite an interesting result. It was found that there was no significant difference of the ecological attributes values existed between the sites (Table 5). There was no significant difference in the ecological attributes between the littoral zones at all the sites (Table 6 to 8). However, it was observed that at the sampling site Dwarka did not show any significant difference in between vertical zones in case of population density and frequency (Table 9 to 11). While, at the other sampling sites have been showed high differences in ecological attributes between zonal distributions. It is possible that the coastal characteristics played an important role for the distribution pattern of this animal at the all stations giving the significant difference (Underwood and Chapman, 2000). The results of the ecological attributes confirmed that *Turbo coronetus* is versatile and mobile gastropod which can rapidly migrate from adverse habitat condition to a better one (Underwood, 1998). The contrasting coast characteristics of the Saurashtra coast is reflected on the local migration of this species which is ultimately patterned the observed results.

5.4.5. Turbo intercostalis

The distribution of *Turbo intercostalis* in the intertidal belt of selected locations shows uniform and solitary. As they are mostly found in the middle and lower littoral zone, so getting an encounter with this group was a rare occurrence. They prefer small but deep rock pores or openings where they can fix themselves singly either with the base or within the rock fold (Kelaher et al., 2001). At the intertidal belt of Saurashtra coast, though rock condition of the upper and middle zone provides sufficient suitable holes to dwell at, still the local people use these as food. Gastropod species favours the substratum for the high proliferation (Anbuchezhian et al., 2009). The animals are equipped with well-developed shell system and that helps them to sustain quite easily at changing condition of the atmosphere.

This species found mostly in middle littoral followed by lower littoral zone at all the sampling sites. However, a very low number encountered at Kodinar was due to the fact that, they were found to be at lower middle or lower littoral zone which was quite inaccessible. They are well protected with shell and show a wide range of food habitat. That’s why, the change in temperature and salinity did not found to leave any significant difference in population (Misra and Kundu, 2005; Vaghela et al., 2010). However, at Veraval the biggest problem they face is the competition with *Mancinella bufo*. These gastropods share the same features and also the same habitat to that of *Turbo intercoastalis*. Thus, the zones where *Mancinella bufo* occurs, enormously, *Turbo intercoastalis* found to be very less. It was also reported by earlier work to this same area (Misra and Kundu, 2005). It was observed from the present investigation that the population density, abundance and frequency values did not show any definite trend at all the sampling sites (Table 5). From the ANOVA, it is evident that there is no significant difference of the ecological atrributes existed between the sites as well as among the seasons. In this case, it can be presumed that the differences in the coast characteristics as well as the habitat preference of this species played an important role in this matter. The results of ANOVA revealed that there was significant difference of the population density value existed between the zonation in all the sampling sites (Table 9). The population density and frequency values have been showed statistically significant differences between zonal distributions (Table 9).

5.4.6. Nerita albicella

The distribution of *Nerita albicella* was not exclusively depending on the substratum pattern. As they can accommodate themselves on varying substratum conditions, so in this case, food availability plays the most prominent role. The animals largely found to occur randomly at patches where population of green algae was higher. However, in case of selected sites, they were observed from upper littoral zone. As the animals are restricted to the upper and middle zone, and a successive upper middle zone requires at least four sampling in between, it is obvious that the ecological attributes was supposed to the distribution was uniform in the upper and middle littoral zone. The distribution pattern of this species was high at upper littoral zone followed by middle littoral zone probably due to the cause of competition for food and space with othe species, which are quite common at the rocky intertidal zone (Dayton, 1971; Underwood, 1981).

The results of present investigation revealed that population density and abundance values were found maximum at Dwarka sampling site. This may be due to the substratum on which this species dwell differs at all the sites from the point of both vertical and horizontal positions. At Dwarka, the intertidal belt is in the form of a gradual plane with pools and creeks at about regular interval. These conditions have been provided room to these animals to move along with the upcoming water during high tide. That makes a uniform distribution of the species at Dwarka as there is extra benefit to be obtained from the substratum. This species, being the dweller of the upper littoral zone, rather to the spray zone, the density is mostly a reflector of the atmospheric physical factors, the degree of tidal harshness (Vaghela et al., 2010). However, at Veraval sampling site this species was observed more in the middle littoral followed by upper littoral zone. Similar trend was recorded in case of Kodinar and Mangrol throughout the study time. This is possibly due to the upper portion of the intertidal belt at those sites is generally covered with an admixture of silt and sand studded with pieces of broken shells and the intertidal pools in the upper littoral zone have a thin layer of sand settled over the rocky. As the upper and especially middle littoral zone mostly covered by algae due to this particular characteristic of intertidal zone provide most scattered place for this species. The statistical analysis proved that there was no any significant difference in zonal distribution at any of those sampling sites (Table 9 to 11).

5.4.7. Rhinoclavis sinensis

Rhinoclavis sinensis, a small gastropod species mostly grazes on the pheophycae and rarely seen in the upper littoral and spray zones. This species prefers lower parts of middle littoral zones and lower littoral zones. The species occupies upper littoral zones during the study period possibly attractive the advantages of the incrusted brown algae present on upper littoral zones, relatively free of competition. The ecological attributes was observed maximum at Dwarka than the other sites. The population density did not show any clear seasonal variations. However, during summer season decline values of the population density have been found. At all the sites the population abundance showed maximum values during post monsoon when the temperature and pressure of water is moderate (Misra and Kundu, 2005).

At the sampling site Dwarka, the intertidal belt is in the form of a gradual plane with pools and creeks at about regular interval, whereas at other sites, it is in the form of steep vertical rock with very less number of pools and almost no creeks. This condition did not provide any space to these animals to move along with the upcoming water during high tide. Physical processes are also important in freeing space, especially in removing older and larger prey which have escaped predation by virtue of their size, but which often become more vulnerable to dislodgement by waves as they age (Crowe and Underwood, 1999).

At the sampling site Kodinar, this species found in middle littoral zone followed by lower littoral zone to some extent it recorded in upper littoral zone during winter season. The available intertidal zone of Kodinar is hard flat rocky littoral area having small sized depressions in interspersed with many rocky pools and puddles. The intertidal belt is interrupted by many small tide pools, this type of substratum provide a better condition for this species (Menge and Sutherland, 1987). On the other side the substratum of Veraval coast is mainly rocky with few sandy patches. The lower littoral zone of Veraval ends up at steep vertical decline towards subtidal zone. The intertidal belt of this area is not uniform and exposure of this predominantly rocky shore is not significantly long. The results of ANOVA showed that there did not show any significant differences in ecological attributes between each sites (Table 5).

The selected Molluscan species characterized by spatial and temporal changes in population ecology. In the present study distribution pattern of the gastropods species seems to be governed by characteristics of environment conditions. In this present study higher values of ecological attributes were recorded during post-monsoon and winter season at almost all the sampling sites. This could be due to low temperature with stable environment of this season (Saravanakumar et al., 2007). In the west coast, post-monsoon seasons were registered by high macrofaunal density (Ansari et al., 1986; Kumar, 2001). Another probably a reason is that of high algal vegetation on the intertidal belt with good canopy of the selected study locations during this particular season. Low ecological attributes found during summer followed by monsoon season. It was apparently during monsoon season due to the effect of heavy rainfall. Similarly Saravanakumar et al. (2007) reported in case of macrobenthos in the Gulf of Kachchh. In Saurashtra, monsoon is predicted by hot dry weather prevailing in months of March to June.

Turbo intercoastalis takes shelter in deeper areas in the intertidal areas in the intertidal pools and puddles, avoiding direct sunlight. The solitary turbinid mollusc was more or less uniform distributed along the intertidal zones. *Trochus radiatus* is the only species that was significantly vary spatially and temporally in case of various ecological attributes. At Saurashtra coast, only few sampling sites like Kodinar and Mangrol have the ideal condition for the survival of this species. In these two areas, *Thochus radiatus* were found to be in higher number. More disturbed water generates a higher current on the shore, and water current regulates *Turbo sp.* and *Trochus radiatus* spawning and breeding to a greater extent (Grange, 1976). This may be a possible reason of higher ecological attributes of this species at Kodinar and Mangrol.

The substratum condition is quite different at the each sampling sites and it reflected on ecological attributes. As these groups of animals move with the water current, the seasonal variations in tidal height and force played a role in their distribution (Underwood and Chapman, 1998). The difference was quite prominent that brought with the change of tidal height during four seasons. It is possible that the distribution at the different sampling sites was regulated by physical factors in a large scale.

Density values of *Conus miliaris* showed clear seasonal variations. However the density and abundance values was higher at Mangrol than the other sites because of the intertidal belt of Mangrol sampling site mostly covered by chlorophycae whereas the other sites harmed by such anthropogenic disturbance like harvesting the seaweeds for pharmaceutical and other use. The structure and dynamics of the macrofauna from the intertidal zones could be related to fluctuations in the availability of food resources (Rossi et al., 2001). Intertidal organisms may benefit from drifting algal mats as a key resources and its availability can affect diversity and abundance of intertidal animals (Norkko and Bonsdorff, 1996; Kelaher and Levinton, 2003).

The result of the present study reveals significant spatial and temporal variations in between the same littoral zone of each sampling sites in case of any ecological attributes. While in mean population density and abundance, did not show any clear variations between sampling locations. It is possibly due to the offered rocky substratum condition and more or less algal vegetation was varied on the intertidal belt among all three littoral zones. In addition, that nature of substratum, flatness of intertidal area, which reduce the wave action, provide small pools and puddles across the different intertidal zone (Misra and Kundu, 2005). In case of exacting site Veraval, the substratum mainly rocky one with steep slope from intertidal to subtidal zone causing faster and higher mixing rate of wastewater and pollutants released from the port, fishery (Misra and Kundu, 2005).

High species diversity occurs on these shores because of the continued reduction of superior competitors and the renewal of the major resource required by the sessile fauna and flora space on the rock surface. Physical processes are also important in freeing space, especially in removing older and larger prey which have escaped predation by virtue of their size, but which often become more vulnerable to dislodgement by waves as they age (Crowe and Underwood, 1999). This effect is often amplified when waves move large objects, such as floating logs.

The intermediate disturbance hypothesis (Caswell, 1978) suggests that at low levels of disturbance, certain competitive species will predominate and hence diversity will be low. At intermediate levels of disturbance, no one species will predominate and diversity will be high. As disturbance increases further, only a few highly tolerant or very opportunistic species will occur. This hypothesis has been tested in elder fields (Sousa, 1979) where stable boulders have a low-diversity community of dominant plants; highest diversity occurs on boulders which get turned by storms occasionally, as succession is halted and restarted but proceeds beyond the early pioneer species phase.

Intertidal mollusca may be found in a wide range of habitats, tide pools, puddles and rocky areas of exposed coast lines and sand flats, available in these areas. The rocky substratum of the Saurashtra peninsula is very disturbed and interrupted surface to survive for both the animals as well as the vegetation. The lower littoral portion, being very sharp cut meeting the subtidal belt generates a very strong wave force.

The vegetation is to be quite healthy in the pools of the middle and lower littoral zones. At the upper littoral zone green algae, *Ulva lactulata* and *Ulva facilata* is the most predominantly along these coastal belt. The lower belt is dominated by the blue as well as green algae. Furthermore it is also covered with green, brown and red algae at some places like Dwarka and Mangrol. These variations may be the intertidal belt of Dwarka consisted of large rocks and boulders and at Mangrol site is interspersed with many tide pools, puddles, crevices and small channels with occasional sandy patches.

The upper littoral zone of Veraval much differed from that of any other sites. Intertidal belt of Veraval is consisted of smooth surfaced, dominated by rock pools. As Veraval upper littoral zone is expended up to the sandy beach beyond the Upper littoral zone, so the wave brings the spores to fan beyond the upper littoral zone, ultimately ends up with depositing at dry sand, thus chances of propagation get lest. While, the intertidal belt at Mangrol, the spray zone may not offer much algal vegetation.

The distribution of the snails is controlled by the substratum characteristics on which they dwell. The intertidal belt of the study site has its peculiar characteristics. The substratum type is only distinction between these four sampling sites as well as zones in those of the particular sampling site. These differences in substratum type might be acting as a result of variations in macrofaunal community and predominantly in their habitat preference on that of the particular area. With high grade of base selective and sessile are restricted to any particular zone (Raghunathan et al., 2004; Misra and Kundu, 2005).

In case of middle and lower littoral zone, this same situation also occurred. At most of the coast of Saurashtra, the rim of the intertidal zone meets the subtidal portion so sharply and the slope on the middle as well as lower zone is so less that virtually it provides no difference between the middle and lower littoral zones and not much possibility of migrates towards. The typical spray dwellers are found to roam over the upper and middle littoral zone. However, as mentioned earlier, the smoothness and the size of rock pool play the major role in animal distribution (Misra and Kundu, 2005).

Suralittoral zone of all the sampling sites was predominantly covered by small sized limpets and *cellena radiata*, which required wider, smoother opening on rock surface because of that these animals were found mostly on the spray zone and also on the upper littoral zone, where weathering and erosion of rock is moderately low than the middle and lower littoral zones. Such a species like, *Turbo coronetus* and *Astrea stellata* are always recorded on the wall of small pools and the cracked rock wall. Early work on rocky shores showed the importance of grazers and predators in structuring communities by preventing domination by fast-growing competitive superiors. In some communities keystone species are very important but in others their importance has been issued. There is also evidence that many communities are nonhierarchical, with complex suites of positive and negative interactions between species, particularly where interactions are lightly balanced, and stochastic factors (e.g. physical disturbance or fluctuations in recruitment) are important in these situations. The importance of different physical and biological processes will vary with position on the major environmental gradients on rocky shores. The recruitment regime will also be important in influencing the intensity and outcome of interactions between species and in generating fluctuations.

The effects of competition between species of intertidal gastropods have been investigated in several regions and on many occasions these studies have shown that inter and intra-specific interactions can clearly lead to a reduction in density of each species (Underwood, 1984; Lasiak and White, 1993). In addition, many of these studies have revealed asymmetric inter-specific competition with the existence of a superior competitor (Connell, 1983). Under these circumstances, coexistence of species has been attributed to the intense or relatively higher intra-specific competition of the superior competitor and according to Underwood (1992), competitive exclusion of one species by another is extremely unlikely to occur for shallow coastal grazers.

5.5. Impact of Heavy Metal on Key Molluscan Species

From the environmental point of view, coastal zones can be considered as the geographical space of interaction between terrestrial and marine ecosystem that is of great importance for survival of large variety of plants, animals and marine species (Castro et al., 1999; Hayette et al., 2006). Adverse anthropogenic effects on the coastal environment include eutrophication, heavy metals, organic and microbial pollution and Oils spills (Boudoureresque and Verlaque, 2002). Heavy metals pollutants are conservative and often highly toxic to marine biota they have been shown to be an important group of toxic contaminants because of their high toxicity and persistence in all aquatic system, cadmium, copper and zinc are metals with most potential impact that enter the environment in elevated concentrations through storm water and waste water discharges as a consequence of agriculture and industrial activity (Beldi et al., 2006). It is obvious that the concentrations of heavy metals in marine algal species are several orders of magnitude higher than the concentrations the same metals in seawater (Donat and Dryden, 2001). The concentration of metals found in seawater from different sampling sites showed more or less variations throughout the season. It is generally agreed that heavy metal uptake occurs mainly from water food and sediment. However, effectiveness of metal uptake from these sources may differ in relation to ecological needs and metabolism of animals and concentrations of the heavy metals in water, food and sediment as well as some other factors such as salinity, temperature, interacting agents.

The increased accretion of anthropogenic trace in marine environment at the Saurashtra coast is somewhat more or less desirable by industrialization. In general heavy metal concentrations were higher at Kodinar and Veraval sampling sites than those of other sites. Sampling site of Kodinar located near the jetty of cement factory. While at Veraval sampling site the largest fishing port as well as such industries are available near the coastal area. It was also observed that metal concentration found to be higher than the allowable limit (0.02 mg/l). The abrupt increase in trace metal concentration is due to the surface runoff and contribution of industrial and sewage discharge to the coastal system Vaghela et al., 2010). Such high concentration of cadmium and cobalt could result in severe health hazards to the marine biota (Selvakumar et al., 1996).

The regression analysis showed that a significant correlation between density value of *Trochus radiatus* and lead at Dwarka (Table 12), but not at any other sites. Heavy metal showed no significant effect on population density of any species at sampling site Dwarka (Table 12). In case of zinc and copper concentration in seawater have been considerable relationships with the density values of *Trochus radiatus* and *Rhinoclavis sinensis* respectively at Mangrol site (Table 13). The abundance values of *Nerita albicilla* and *Mancinella bufo* also showed significant correlation in case of cadmium and copper concentration in seawater samples. The sampling site Mangrol is a small hamlet, however they have maximum facilitates for various types of port activity and fishing but not a proper maintenance of this coastal area. Due to this reason somewhat the concentration of such metals was found to be higher than the other sites, like that Veraval is also well known as a largest fish landing site. At the Mangrol and Veraval site increased in the copper concentration is due to the surface runoff and contribution of industrial discharge to the coastal ecosystem. Similarly at Kodinar the lead concentration in seawater showed a significant correlation with population density of *Mancinella bufo* and *Nerita albicilla*, while in case of cadmium in seawater correlate with abundance value of *Turbo coronetus* (Table 15). It was also found that an overall increase in the concentration of heavy metals associated with the decrease in species abundance was observed during present study. Similar results observed in case of Tolo Harbour (Chen et al., 2010). However, from the present investigation it was also found that from the results not a single factor like trace elements affect the entire coastal system.

5.6. Anthropogenic Pressure

As rocky shores are among the most accessible of the marine environments, they can be visited by large numbers of people, particularly shores near major cities, for aesthetic reasons, to collect food or bait or for fishing. Harvesting for food and bait can disrupt rocky shore communities, and also deplete some species while allowing for increase in dominance of other species. Coastal development will change hydrology and topography of areas and thus the characteristics of rocky shore communities. Alteration of water quality and input of pollutants will impact on rocky intertidal communities (Miller and Auyong, 1991).

In the intertidal region vital ecological communities can found, emphasizing the importance of the coastal area as a habitat (Jenkins et al., 2001). The intertidal area is strongly influenced by the tides, which allow sea levels to fluctuate between high and low. Tidal variations affect the number of species immersed by the sea, therefore dictating the regions ecology (Littler and Kitching, 1996). The extent of stress experienced by the region is dependent on the intensity of various environmental factors, of which vary with latitude (Lewis, 1972).

For many years humans have substantially affected Intertidal zones across the globe. Oil spills, nutrient and pesticide pollution and the introduction of exotic species have all had very significant impacts on intertidal communities (Crowe et al., 2000). However, it is the impacts of recreational stresses on intertidal zones that have become a more important focus of intertidal ecological research over the past decade (Brosnan and Crumrine, 1994). Industries remain one of the major competitors for the use of coastal region. The importance of industrial sectors in Indian economy is growing over the years after independence. Major advantages of selecting coasts as the industrial destination include: transportation, water use and waste disposal. Many of the highly polluting industries are located in the coastal areas.

Dumping industrial wastes in the sea is very common in these areas. According to an estimate, most of the industrial and land based sources: remaining 20% comes from atmospheric sources. Chemicals and heavy metals are found in the industrial wastes. They affect human and severely damage the marine life. Industrial wastes are toxic and remain in the sea for a long time and accumulate in the marine organism. The most serious concerns world over involve Persistent Organic Pollutants (POPs) which have become common in the ocean environment due to industrialization along the coastal lines. They tend to linger in the living tissues of marine species and become more concentrated as they move up the food chain. The industrial toxins can kill or contaminate marine life.

Freshwater runoff affects coastal ecosystems and communities in many ways. The delivery of sediment, nutrients, and contaminants is closely linked to both the strength and timing of freshwater runoff. Salinity gradients are driven by freshwater inputs into estuaries and coastal systems, and have strong effects on biotic distributions, life histories, and geochemistry. Coastal runoff also affects circulation in estuaries and continental shelf areas, and increases in runoff have the potential to increase the vertical stratification and decrease the rate of thermo-haline circulation by adding more freshwater to the system. In the event that increased river flows result from climate change, more suspended sediments could be transported into the coastal regions, increasing the upper layer turbidity and potentially reducing available light to both plankton and submerged aquatic vegetation. Increased river flows could also increase the flux of nutrients and contaminants into coastal systems, which influence eutrophication and the accumulation of toxins in marine sediments and living resources. Both increased temperatures and decreased densities in the upper layers might also reduce the vertical convection enough to prevent oxygenation of the bottom waters, further contributing to anoxic conditions in the near-bottom waters (Justic´ et al., 1996). Decreased freshwater inflows into coastal ecosystems would be likely have the reverse effect, reducing flushing in estuaries, increasing the salinity of brackish waters, and possibly increasing the susceptibility of shellfish to diseases and predators.

The natural sources of heavy metals in coastal waters are through river runoff. The mechanical and chemical weathering of rocks serves as another major source. In addition, components washed into the atmosphere, through rainfall, windblown dust, forest fires and volcanic particles also added to this. The natural concentrations of metals in sea water are very low and the possibilities of contamination are high. Virtually, all industrial processes involving water are potential sources of metallic contamination in coastal waters. The discharge of human sewage and garbage into the coastal waters is practiced throughout the world. The sewage may or may not have had some treatment before discharge. It adds a large volume of small particles to the water and also large amounts of nutrients. In small volumes and with adequate diffusing pipes, it is difficult to detect long-term effect on the communities of the open coast. In large volumes and in semi-enclosed embayment, the effect can be devastating.

Coastal areas in Saurashtra peninsula are attractive to tourism, industries, fishing and many more activities. These activities in the coastal areas give rise to competition and therefore conflicts between human uses. Furthermore, these conflicts may occur between human activities and the intertidal zone biota. Dumping and discharging of pollutants into the sea, nutrient and runoff from land and rivers, fallout of chemicals carried by the wind from land-based sources are some of the major contaminants affecting marine ecosystems. Nontoxic solid wastes and marine debris cause significant mortality among marine species like plastic bags, fishing lines, and other debris causing slow. The coastal zone of Saurashtra coastline along the Arabian Sea has a broad continental shelf thereby extremely rich in intertidal and subtidal flora and fauna. The resources available in the coastal region for people, with varying interest industrial, tourist, livelihood making their way into the coastal zone. This trend has developed a population out break and has made the environment fragile because it needs more space, infrastructure which creates extra pressure to the coastal environment.

The Saurashtra coastal area supports some of the rich fishing ground in India. Saurashtra coastline also contains numerous industrial settlement and pilgrim tourist area especially near the coast which produce human activities that interfere on the coastal ecosystem. With this expansion, as well as increased wealth and affluence, there are rapidly increasing demands on coastal and marine resources for both aesthetic enjoyment and economic benefits. This large and growing human population pressure in coastal areas is responsible for many of the current stresses to coastal resources. Impacts of various human activities in the coastal zone are very complex and difficult to assess as there are no direct method to evaluate them quantitatively. Population pressures from further inland can also have detrimental impacts on coastal resources. Effluent discharges as well as agricultural runoff have caused significant nutrient over-enrichment in many coastal areas. Sewage and siltation are significant contributors to coral reef degradation. The effects of various activities vary considerably from case to case or type to type not only due to the variety anthropogenic activities and sources but also due to the specificities of the receiving micro environmental and prevailing hydro morphological conditions (Vaghela et al., 2010). Therefore, overall anthropogenic effects in terms of industrial pressure, domestic sewage, port activities and tourism on the coastal region are a mosaic type composed of different types of inputs and mechanisms (Misra and Kundu, 2005).

The development of the Saurashtra region was driven solely by the trading possibilities offered by its long coastline and ports. It would appear that today the problems consequent to the high degree of industrialization along the Saurashtra coastline are being addressed with even more industrialization. There are two developed fishing harbours with allied at Veraval and Mangrol, which face 62 % fish production out of the total fish production. The industrial groups that have grater dominance are cement; food industry and the existing port with facilitate import or export of fish and fishery products, fertilizers, salt, cement, soda ash and lime stone etc. With respect to coastal Saurashtra, the minerals present include limestone, bauxite, lignite, chalk and bentonite amongst others. Saurashtra has a number of key minerals with significant economic potential. It is already exploiting its rich mineral resources. However, there are other key minerals present in the region that have significant potential present, namely, lignite and bentonite. Gujarat has a large mineral resource base and 4^{th} largest producer of limestone in the country.

It was also observed the harvesting of marine algae for industrial and for the other at various parts of Saurashtra coast. As it appears, the harvesting of marine algae for the different industrial purposes was singular most important devastating tourism activity which seriously affects the marine life. Marine algae are relatively well known in the intertidal diversity and economic life of humans and ecosystems. The use of algae as food, animal fodder, fertilizers, as raw materials in the industrial product have been received much attention in Saurashtra coast. In addition, commercially important agars are extracted from red and brown algae. Agars obtained from *Gelidium sp.* are used extensively in microbiology and tissue culture. The agar from *Gracilaria sp.* is used mainly in foods. Kodinar coastline is influenced by a cement factory and a sugar mill. The human activity near the coast is not much in terms of direct contact of the people to the coastline. However, dumping of waste from these industries was the main anthropogenic pressure. The Dwarka sampling site in notoriously use by the visiting human population which freely perform all kinds of notorious human activities in this coast. The most seriously consequent of this tourism related human activities are habitat destruction which adversely and more permanently affects the coastal ecosystem. In case of Mangrol which is relatively unaffected area.

Tables

Table 5. Result of the one-way ANOVA of different ecological attributes values between the sampling sites. The test denotes spatial variations of the seven species studied. The f-critical value is 3.490, and * denotes significance at P < 5 %.

	Density	Abundance	Frequency
Turbo coronetus	0.8038	0.1812	1.1321
Turbo intercostalis	0.2148	0.0334	0.2782
Conus miliaris	1.1114	1.2953	0.9716
Mancinella bufo	0.7991	2.2159	0.5536
Rhinoclevis sinensis	0.3442	0.2436	0.4790
Trochus radiatus	12.2882*	2.3375	15.3395*
Nerita albicella	0.6148	1.1326	0.5799

Table 6. Results of the ANOVA between the mean density values of the species studied, in each of the littoral zone, of the four sampling sites. The f-critical value is 3.490, and * denotes significance at P < 5 %.

	Upper	Middle	Lower
Mancinella bufo	4.69697*	0.86400	0.66234
Conus miliaris	1.80992	0.48768	0.69194
Trochus radiatus	10.36000*	21.91512*	4.02299*
Turbo coronetus	2.46626	0.41695	0.41026
Turbo intercostalis	0.22857	2.67123	0.19540
Nerita albicilla	0.68338	0.80366	0.39301
Rhinoclavis sinensis	1.05204	0.50665	0.09686

Table 7. Result of the ANOVA between the mean abundance values of the species studied, in each of the littoral zone, of the four sampling sites. The f-critical value is 3.490, and * denotes significance at P < 5 %.

	Upper	**Middle**	**Lower**
Mancinella bufo	1.41935	6.52253*	0.67740
Conus miliaris	0.78788	0.53191	0.71900
Trochus radiatus	1.34865	1.30240	2.68671
Turbo coronetus	0.17260	0.06245	0.54877
Turbo intercostalis	0.21793	0.08607	0.26837
Nerita albicilla	1.71504	0.83888	0.24203
Rhinoclavis sinensis	0.11781	0.35327	0.24450

Table 8. Result of the ANOVA between the mean frequency values of the species studied, in each of the littoral zone, of the four sampling sites. The f-critical value is 3.490, and * denotes significance at P < 5 %.

	Upper	**Middle**	**Lower**
Mancinella bufo	3.52941*	0.33735	0.69697
Conus miliaris	2.40594	0.11950	0.69849
Trochus radiatus	7.50000*	19.87100*	2.86617
Turbo coronetus	2.54362	0.85714	0.22449
Turbo intercostalis	0.23077	5.35294	0.29185
Nerita albicilla	1.44928	0.49664	0.32751
Rhinoclavis sinensis	2.49333	0.47312	0.05854

Table 9. Result of the ANOVA of the mean density values of the species studied, in four sampling sites between each of the littoral zone. The f-critical value is 4.256, and * denotes significance at P < 5 %

	Dwarka	Mangrol	Veraval	Kodinar
Mancinella bufo	1.79508	4.78947*	6.64486*	4.25654*
Conus miliaris	4.11039	2.45455	1.91457	3.15207
Trochus radiatus	1.94845	5.62326*	7.23913*	9.29679*
Turbo coronetus	3.19469	18.66867*	14.78182*	7.67308*
Turbo intercostalis	4.34237*	8.85799*	11.4482*	6.55200*
Nerita albicilla	0.93830	0.36275	0.86788	2.30045
Rhinoclavis sinensis	1.31081	0.53390	0.70558	1.04464

Table 10. Result of the ANOVA of the mean abundance values of the species studied, in four sampling sites between each of the littoral zone. The f-critical value is 4.256, and * denotes significance at P < 5 %.

	Dwarka	Mangrol	Veraval	Kodinar
Mancinella bufo	1.15035	0.04620	15.04787*	0.14813
Conus miliaris	1.71768	3.62698	2.47826	0.60122
Trochus radiatus	1.74236	2.64378	1.97233	1.39609
Turbo coronetus	0.92895	0.92994	0.89450	1.12649
Turbo intercostalis	0.82052	5.16958	3.54674	2.11895
Nerita albicilla	0.82688	0.16369	0.45472	1.31298
Rhinoclavis sinensis	0.48675	0.47752	0.13054	0.67274

Table 11. Result of the ANOVA of the mean frequency values of the species studied, in four sampling sites between each of the littoral zone. The f-critical value is 4.256, and * denotes significance at P < 5 %.

	Dwarka	**Mangrol**	**Veraval**	**Kodinar**
Mancinella bufo	1.74490	7.63953*	2.84810	6.44118*
Conus miliaris	3.48462	1.23158	2.22137	4.39806*
Trochus radiatus	1.05738	4.03030	4.90000*	4.94628*
Turbo coronetus	3.50420	9.91603*	13.89655*	6.31132*
Turbo intercostalis	5.62069*	6.71956*	15.27273*	6.51429*
Nerita albicilla	1.30570	0.78610	0.89441	1.83871
Rhinoclavis sinensis	1.86000	0.73256	1.83871	1.74820

Table 12. Results of regression coefficient (R^2) analysis between seasonal density and mean value of heavy metals at sampling site Dwarka, (*p<0.05).

	Pb	**Zn**	**Cd**	**Cu**
Mancinella bufo	0.176	0.549	0.116	0.070
Conus miliaris	0.176	0.515	0.002	0.280
Trochus radiatus	0.896*	0.012	0.010	0.098
Turbo coronetus	0.307	0.361	0.161	0.041
Turbo intercostalis	0.212	0.436	0.249	0.009
Nerita albicilla	0.023	0.650	0.488	0.027
Rhinoclavis sinensis	0.154	0.583	0.098	0.084

Table 13. Results of regression coefficient (R^2) analysis between Seasonal density and mean value of heavy metals at sampling site Mangrol, (*$p<0.05$).

	Pb	**Zn**	**Cd**	**Cu**
Mancinella bufo	0.003	0.185	0.199	0.734
Conus miliaris	0.000	0.147	0.145	0.719
Trochus radiatus	0.031	0.869*	0.051	0.006
Turbo coronetus	0.191	0.576	0.001	0.203
Turbo intercostalis	0.000	0.062	0.098	0.728
Nerita albicilla	0.007	0.111	0.191	0.785
Rhinoclavis sinensis	0.023	0.100	0.250	0.833*

Table 14. Results of regression coefficient (R^2) analysis between Seasonal density and mean value of heavy metals at sampling site Veraval, (*$p<0.05$).

	Pb	**Zn**	**Cd**	**Cu**
Mancinella bufo	0.591	0.045	0.045	0.199
Conus miliaris	0.537	0.019	0.071	0.158
Trochus radiatus	0.063	0.387	0.611	0.990
Turbo coronetus	0.005	0.404	0.196	0.000
Turbo intercostalis	0.003	0.331	0.237	0.000
Nerita albicilla	0.021	0.206	0.159	0.017
Rhinoclavis sinensis	0.008	0.539	0.357	0.041

Table 15. Results of regression coefficient (R^2) analysis between Seasonal density and mean value of heavy metals at Sampling site Kodinar, (*p<0.05).

	Pb	Zn	Cd	Cu
Mancinella bufo	0.286	0.707	0.187	0.004
Conus miliaris	0.286	0.707	0.187	0.004
Trochus radiatus	0.035	0.740	0.252	0.069
Turbo coronetus	0.033	0.647	0.180	0.342
Turbo intercostalis	0.013	0.514	0.470	0.045
Nerita albicilla	0.185	0.799	0.157	0.006
Rhinoclavis sinensis	0.193	0.635	0.309	0.000

Table 16. Results of regression coefficient (R^2) analysis between Seasonal abundance and mean value of heavy metals at sampling site Dwarka, (*p<0.05).

	Pb	Zn	Cd	Cu
Mancinella bufo	0.285	0.509	0.042	0.087
Conus miliaris	0.175	0.007	0.609	0.229
Trochus radiatus	0.633	0.047	0.139	0.005
Turbo coronetus	0.586	0.077	0.134	0.030
Turbo intercostalis	0.357	0.095	0.385	0.017
Nerita albicella	0.095	0.273	0.655	0.113
Rhinoclavis sinensis	0.149	0.485	0.326	0.001

Table 17. Results of regression coefficient (R^2) analysis between Seasonal abundance and mean value of heavy metals at sampling site Mangrol, (*$p<0.05$).

	Pb	Zn	Cd	Cu
Mancinella bufo	0.030	0.112	0.282	0.839*
Conus miliaris	0.007	0.668	0.319	0.280
Trochus radiatus	0.136	0.289	0.319	0.003
Turbo coronetus	0.078	0.035	0.332	0.928*
Turbo intercostalis	0.014	0.090	0.212	0.817*
Nerita albicella	0.520	0.080	0.937*	0.510
Rhinoclavis sinensis	0.153	0.106	0.540	0.887*

Table 18. Results of regression coefficient (R^2) analysis between Seasonal abundance and mean value of heavy metals at sampling site Veraval, (*$p<0.05$).

	Pb	Zn	Cd	Cu
Mancinella bufo	0.491	0.025	0.407	0.181
Conus miliaris	0.444	0.018	0.379	0.000
Trochus radiatus	0.463	0.855*	0.138	0.141
Turbo coronetus	0.239	0.209	0.035	0.100
Turbo intercostalis	0.296	0.770	0.149	0.071
Nerita albicella	0.114	0.562	0.126	0.007
Rhinoclavis sinensis	0.164	0.581	0.373	0.018

Table 19. Results of regression coefficient (R^2) analysis between Seasonal abundance and mean value of heavy metals at sampling site Kodinar, (*$p<0.05$).

	Pb	Zn	Cd	Cu
Mancinella bufo	0.897*	0.268	0.027	0.350
Conus miliaris	0.640	0.026	0.405	0.566
Trochus radiatus	0.059	0.350	0.639	0.000
Turbo coronetus	0.046	0.053	0.931*	0.050
Turbo intercostalis	0.054	0.618	0.167	0.390
Nerita albicella	0.913*	0.223	0.042	0.402
Rhinoclavis sinensis	0.356	0.301	0.498	0.115

Table 20. General coastal water quality standard for aquatic life (Limiting value for concentration in mg/l), (As per EPA, 1986).

Parameters	Standards
Cadmium	0.01 mg/l
Lead	0.1 mg/l
Copper	0.02 mg/l
Zink	0.1 mg/l
Cobalt	0.005 mg/l
Chromium	0.1 mg/l

Results of the Hypothesis Tested

Hypotheses tested in this proposed work were made in Null form. The results of the present investigations ratified and tested these hypotheses which are as follows:

NO.	HYPOTHESIS TESTED	RESULT
1.	There will be no significant spatial and temporal variations in the gross macrofaunal diversity between the selected study area in the South Saurashtra Coastline.	**True** The macrofaunal diversity remains almost same in the coasts studied as the coastline is continuous off Arabian Sea
2.	The population density or abundance will not be significantly influenced in the spatial condition when placed against the time scale.	**True** in some key species (*M. bufo, N. albicella, R. sinensis*) **False** in some key species (*C. miliaris, T. radiates, T. coronetus, T. intercoastalis*)
3.	The ecological pattern of the macrofaunal population will not be influenced by the time scale.	**False** The macrofaunal population showed seasonal fluctuations
4.	Spatial distribution of the intertidal organisms will not be responsive against the pressure made on the system by anthropogenic activities.	**True** Spatial distribution and population ecology of key intertidal macrofauna were not seriously influences by anthropogenic pressure barring few localized cases like points of effluent and sewage discharge, immediate vicinity of ports and localities.

Chapter - VI: Summary

The present study was undertaken to set up an innovative trend of monitoring of the human-nature interaction and its effect on the natural system to set up the openings of the future study on this tract at this area. In this context, a detailed study on the Saurashtra coast line, one of the biggest one in India desired a detailed monitoring to work out the present status of the ecosystem, the threats mounting and impending, natural resistance and adaptation in response to the pressure and a possible negotiation to the neutralize the harsh condition to offer a better tomorrow. The present study deals with the biodiversity and man-made pressure on the coastal health as well wealth of the rocky intertidal macrofauna in four different stations along the Saurashtra coastline. With a view to assess the status of the few key species of intertidal mollusca, the heavy metal contamination of the coast and the interaction between the fauna and anthropogenic activities were investigated. The Western coastal belt of India, these days is considerably being exploited heavily by various kinds of Industries. This study revealed how this is affecting the ecosystem of this area.

Before the selection of study sites, locations of the sampling sites were selected according to a preliminary study of the coastline in view of different anthropogenic pressure on coastal area. Now a day's especially Saurashtra coast is being hot-spot for various mega industries, fishery related opportunities and further more tourism is also one of the related problems on the coastal zone of Saurashtra peninsula. For present investigations four different sites were selected along the South Saurashtra coastline off Arabian Sea, viz. Dwarka, Mangrol, Veraval and Kodinar. Each of these sites were chosen because they are accessible, on the open coast and all these sites, are influenced by the direct pressure of humans and pollutants from both harbors and terrestrial sources. The selected location of Saurashtra coast was surveyed extensively to monitor the coast characteristics, from both physical and biological approach.

Study was intended to conduct the spatial as well as temporal variations of rocky intertidal macrofauna, population ecology of some key molluscan species, heavy metal analysis and anthropogenic impact along the Saurashtra coastline. In this regards, four study sites, Dwarka, Mangrol, Veraval and Kodinar from Saurashtra coastline were selected. These sites exhibit various anthropogenic impacts with different magnitude of human disturbances as seawater quality, community stress, if any, discriminated by population ecology of key mollusca and various statistical methods to the recognized anthropogenic disturbances on molluscan assemblages and water quality in terms of heavy metal from Saurashtra coastline off Arabian Sea.

The reconnaissance survey was made from November 2007 to August 2009. During this period, each sampling sites were survey regularly for the macrofaunal diversity for qualitative assessment. The monthly data were collected for population ecology study during September 2008 to August 2009. Simultaneously during this period sea water samples were also collected for metal analysis. The months were summed up to four seasons viz., winter (December to February), summer (March to May), monsoon (June to August), post monsoon (September to November). It was also observed the different anthropogenic activities along the coastline during this time period.

The study examined the variations in population density, abundance and frequency of key molluscan species between four study localities. The Molluscan species were selected on the basis of their occurrence through the study area. As these were found to be the most prominent one and their presence throughout the season, these organisms were selected. More to that, as they were reported to be non-migrant (Inter coast), so long selection of these would ensure a long term study on the same aspect. As the study area was purely a rocky one, so filter feeders and other such organisms those are usually selected were not taken into consideration to work with on these belt. A close look to the animals shows that these organisms were dominant in all the three zones. So, a detailed study on these could reflect the ecological status of the three zones. The selected animals are: *Mancinella bufo, Conus miliaris, Trochus radiatus, Turbo coronetus, Turbo intercostalis, Nerita albicella* and *Rhinoclavis sinensis*.

The intertidal zone of each sampling sites were surveyed regularly on monthly basis and all the macrofauna and flora encountered were recorded properly. Extensive photography was employed for the identification of the animal species with the identification keys, literature available in the form of books, journals, reports and with extensive use of internet. The complete study was conducted in a non-destructive manner in which the organisms were disturbed to the bare minimum, let alone killing any. All intertidal macrofauna and algae observed were recorded properly and later classified systematically. Thus animals under various phyla were recorded and checklist was prepared.

Foot transect method was primarily used for generating the population database. At all the sites, criss-cross direction was followed to cover the maximum exposed area on the intertidal belt. The visits were made at the lowest tides of the months. Quadrates of 0.25 m^2 were laid while following an oblique direction covering maximum area at almost regular occurrence on the preferred intertidal belt. Quadrate frequency was determined on the basis of the total length of the intertidal area along the sampling site. At the each zone of sampling site, ten quadrates were used to be laid during the study period. The visits are made at the lowest tides of the months. Sampling used to be started with the start of the low tide and attempts were made to finish two sites within the stipulated duration of about four hours.

Sea water samples were collected monthly from each sampling site of the study area. Water samples were collected from directly from the surface in previously acid-washed glass bottle and stored in HNO_3. The sea water samples, analyzed for concentrations of the major trace metals were estimated using an Atomic Absorption Spectrophotometer (AAS). Data was presented in mg/l concentration. The water samples were analyzed for various trace elements based on the procedures described in APHA (1995), Trivedi and Goel (1986) and other literatures collected for this study.

Quantitative estimation of anthropogenic impact is remained a non-conclusive controversial one. Thus, in the present study the various anthropogenic influences on exposed shores and the structural role of macro-invertebrate on the shores were qualitatively demonstrated by field experiments. Extensive field study was regularly carried out along the entire coastal zone of Saurashtra region. The study sites were identified and make a note of the type of various anthropogenic activities such as tourism, fisheries, port activity, industry, sewage and disposal waste. In the present study heavy metals analysis was used for describe the coastal pollution and its effects on the some prominent molluscan species.

The collected monthly data were presented as seasonally for the seasonal approach like winter, summer, monsoon and post-monsoon then calculated statistically like mean and standard deviation. The obtained data were subjected to different statistical analyses for their cumulative acceptability. All the data was calculated automatically by using Microsoft Office Excel software. Significance of spatial and temporal variations was compared by using single factor ANOVA. Regression coefficients analysis was also performed to find out relationship between various metals in seawater and few prominent macrofaunal species within a sampling site, to assess the influence of trace metals on the few indicator species in the intertidal zone.

As far as the macrofaunal diversity is concern, in the present study, amongst four sites, Dwarka showed more macrofaunal diversity on the intertidal belt than the other sites. Mollusca were the most dominant group and platyhelminthes was the least observed group. A clear dominance was observed between the sampling site of Veraval and Kodinar based on the macrofaunal diversity. In the present investigation, a total of 120 species were recorded from the four sampling sites in Saurashtra peninsula. The sponge population was less in all the study sites. They were seen mainly in middle and lower littoral zone, somewhat present in upper littoral but not in dried area. It has been found in group coelenterata that the variation in species was high in lower littoral zone and minimum was in upper littoral zone. The occurrence of the corals in the intertidal zone is restricted between middle littoral and lower littoral zones. Species like *Portis lutea* and *Favia favulus* were recorded mostly in rock pools. The *Zoanthus* population is quite good here. In the pools of rocky beach, sea anemones were found. However, the lower zone consists of big boulders usually covered with *Zoanthus*. Platyhelminthes group comprised three species, which was present in tide pools with the existence of water during low tide and associated with algae. In case of annelida, *Nereis pelagica* and *heteronereis sp.* was present in sandy portion and under the rock in pools and due to its nature of burrowing, rarely came out in the open. *Chetopterus chetopterus, Serpula vermicularis* and *Sabella pavonica* were mostly found in lower littoral zone and attached with rocks. The arthropoda group is prefers to be in association with intertidal algae at upper and middle littoral zone, especially in the pools and puddles. Arthropoda feeds on the Algae as well as zooplankton, thus, vigorous tidal activity of the lower littoral zone might not be a suitable place for them. Group Mollusca showed more or less similar trend in upper and middle littoral zones. This trend may be due to the fact that the mollusca mainly feed on the marine algae and thus, always associated with intertidal seaweeds. Among that eight species of oysters, two species of mussels, 17 species of clams, six species of pearl oysters, four species of giant clams and other gastropods such as *Trochus*, *Turbo* as well as 15 species of cephalopods are exploited from the Indian marine region. In the case of echinodermata species number was less because *Asterina gibbosa* and *Ophioderma brevispinum* inhabiting deep water. But also present in intertidal zone. On the whole, it appears that in general, this area rich in macrofauna and algae. *Ophioderma brevispinum* was communally occurred and the distributed species in this group at almost all the sampling sites.

Mancinella bufo is normally seen associated with green algae in the vertical zones which is a grazer on green algae like chlorophycae as a whole and *ulva lactuca* in particular. This species was found to be more prolific in middle and lower littoral zones at all the sampling locations of this coastline. The middle and lower littoral zones were preferred by this species and small number of individuals was found in the deep pools and puddles on association with green algae during the low tide. Thus the presence of rock pools increases the species richness of the shores. The ecological attributes, density abundance and frequency did not show any significant differences between sampling sites. However, the results of statistical analysis indicated significant variations at the upper littoral zones between four sampling sites of the ecological attributes like density and frequency values. This may be due to the local migration of this highly motile species from upper littoral zones to avoid excessive heat, desiccation and rough tidal activities especially none availability of algal species in the upper littoral zones of each selected sampling sites.

Conus miliaris mostly associated with green algae. It was found from the present study that the intertidal belt of selected locations was generally covered by green and brown algae like *Ulva sp.* and *Sargassum sp.* Therefore, this species migrates from zone to zone for grazing. However the middle and lower littoral zones are most preferable habitat for this species. Due to this reason the ecological attributes was found to be higher in those prefer littoral zones at each sampling sites. As this group of animals move with the water current, the seasonal variations in tidal height and force played a role in their distribution. However the density and abundance values were higher at Mangrol than the other sites because of the intertidal belt of Mangrol sampling site which was mostly covered by green algae. It was more suitable place for this grazer species. The statistical analysis indicates significant difference of the population frequency was observed between littoral zones at Kodinar. This may be due to the flat sloping, gentle wave action on intertidal belt of Kodinar where the vertical zonation is not in existance compared with other sampling sites.

Result showed that the ecological attributes of *Trochus radiatus* were high during each season at sampling site Kodinar. The main reason behind a higher ecological attributes is because the substratum type is somewhat rough and in addition, the intertidal belt have many small sized rock pools which is suitable habitat of this species. One more reason for higher population of this species at that particular area has algal cover over the substratum, which causes its dwellers a better healthy condition. At sampling site Dwarka population of this species was low than the other sites. This may be due to the elevated current and heavy wave action can be exaggerated by pebbles and even large stones being moved around by waves. The encounter rate increased with the decrease of salinity, bright light and temperature. Apart from the substratum type, these two may be the other controlling factor for this group of animals. Results of the ANOVA showed the significant difference existed between sampling sites in case of density and frequency values. The comparison of each of the littoral zone at all the sampling sites the upper littoral zone showed a significant variations in case of population density similarly the middle and lower littoral zones also showed the significant variations throughout the study period. Intertidal assemblages between shores separated by hundreds of kilometers among sites separated by meters found greater variability at small spatial scales relative to larger scale differences among shores.

Turbo cornatus is found mostly on the upper and middle littoral zone of the rocky intertidal substratum and prefer a smooth surface to move on. They occur in the walls of the pools or creeks where water accumulates for a longer duration. Creaks and crevices provide protection from waves and from desiccation, and will increase species richness of a shore and the abundance of the species. The distribution of this species was high at Veraval due to such condition to a relatively large extent. The ANOVA test revealed quite an interesting result. It was found that there was no significant difference of the ecological attributes values existed between the sites. There was no significant difference in the ecological attributes between the littoral zones at all the sites.

However, Mangrol, Veraval and Kodinar have been showed high differences in ecological attributes between zonal distributions. It is possible that the coastal characteristics played an important role for the distribution pattern of this animal, giving the significant difference. The results of the ecological attributes confirmed that *Turbo cornatus* is versatile and mobile gastropod which can rapidly migrate from adverse habitat condition to a better one. The contrasting coast characteristics of the Saurashtra coast is reflected on the local migration of this species which is ultimately patterned the observed results.

The distribution of *Turbo intercoastalis* in the intertidal belt of selected locations shows uniform and solitary. As they are mostly found in the middle and lower littoral zone, so getting an encounter with this group was a rare occurrence. They prefer small but deep rock pores or openings where they can fix themselves singly either with the base or within the rock fold. At the intertidal belt of Saurashtra coast, though rock condition of the upper and middle zone provides sufficient suitable holes to dwell at, still the local people use these as food. They are well protected with shell and show a wide range of food habit. That’s why, the change in temperature and salinity did not found to leave any significant difference in population. However, at Veraval the biggest problem they face is the competition with *Mancinella bufo*. These gastropods share the same features and also the same habitat to that of *Turbo intercoastalis*. Thus, the zones where *Mancinella bufo* occurs, enormously, *Turbo intercoastalis* found to be very less. The population density and frequency values have been showed statistically significant differences between zonal distributions.

The distribution of *Nerita albicella* was not exclusively depending on the substratum pattern. As they can accommodate themselves on varying substratum conditions, so in this case, food availability plays the most prominent role. The animals largely found to occur randomly at patches where population of green algae was higher. However, in case of selected sites, they were observed from upper littoral zone. As the animals are restricted to the upper and middle zone, and a successive upper middle zone requires at least four sampling in between, it is obvious that the ecological attributes was supposed to the distribution was uniform in the upper and middle littoral zone. The distribution pattern of this species was high at upper littoral zone followed by middle littoral zone probably due to the cause of competition for food and space with other species, which are quite common at the rocky intertidal zone. The results of present investigation revealed that population density and abundance values were found maximum at Dwarka sampling site. This may be due to the substratum on which this species dwell differs from at all the sites from the point of both vertical and horizontal positions. At Dwarka, the intertidal belt is in the form of a gradual plane with pools and creeks at about regular interval. These conditions have been provided room to these animals to move along with the upcoming water during high tide.

Rhinoclavis sinensis, prefers lower parts of middle littoral zones and lower littoral zones. The ecological attributes was observed maximum at Dwarka than the other sites. At the sampling site Dwarka, the intertidal belt is in the form of a gradual plane with pools and creeks at about regular interval, whereas at other sites, it is in the form of steep vertical rock with very less number of pools and almost no creeks. This condition did not provide any space to these animals to move along with the upcoming water during high tide. Physical processes are also important in freeing space, especially in removing older and larger prey which have escaped predation by virtue of their size, but which often become more vulnerable to dislodgement by waves as they age. The results of ANOVA showed that there did not show any significant differences in ecological attributes between each sites.

The increased accretion of anthropogenic trace in marine environment at the Saurashtra coast is somewhat more or less desirable by industrialization. In general heavy metal concentrations were higher at Kodinar and Veraval sampling sites than those of other sites. Sampling site of Kodinar located near the jetty of cement factory. While at Veraval sampling site the largest fishing port as well as such industries are available near the coastal area. It was also observed that metal concentration found to be higher than the allowable limit (0.02 mg/l). The abrupt increase in trace metal concentration is due to the surface runoff and contribution of industrial and sewage discharge to the coastal system. Such high concentration of cadmium and cobalt could result in severe health hazards to the marine biota.

The regression analysis showed that a significant correlation between density value of *Trochus radiatus* and lead at Dwarka, but not at any other sites. In case of zinc and copper concentration in seawater have been considerable relationships with the density values of *Trochus radiatus* and *Rhinoclavis sinensis* respectively at Mangrol site. The abundance values of *Nerita albicilla* and *Mancinella bufo* also showed significant correlation in case of cadmium and copper concentration in seawater samples. The sampling site Mangrol is a small hamlet, however they have maximum facilitates for various types of port activity and fishing but not a proper maintenance of this coastal area. Due to this reason somewhat the concentration of such metals was found to be higher than the other sites, like that Veraval is also well known as a largest fish landing site. At the Mangrol and Veraval site increased in the copper concentration is due to the surface runoff and contribution of industrial discharge to the coastal ecosystem. Similarly at Kodinar the lead concentration in seawater showed a significant correlation with population density of *Mancinella bufo* and *Nerita albicilla*, while in case of cadmium in seawater correlate with abundance value of *Turbo coronetus*. It was also found that an overall increase in the concentration of heavy metals associated with the decrease in species abundance was observed during present study.

The results clearly indicate a less human interference at Dwarka. In case of Mangrol which is another relatively unaffected area showed similar results like Dwarka. This coastline is free from any anthropogenic pressure which is evident from its water quality parameters. However, the sampling site at Veraval clearly indicating anthropogenically affected water quality status. The heavy metal parameters at Kodinar which is also affected by anthropogenic pressure in the form of industrial run off showed similar pattern like Veraval. The results suggested moderately influenced water quality at Kodinar compared to that of Dwarka and Mangrol.

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Appendix

Research papers presented

- "Ecological status of few intertidal mollusca of rocky shores of South Saurashtra Coastline, in view of global warming." Presented in Science Excellence-2010, Department of Botany, Gujarat University, Ahmedabad on 9th January 2010.

- "Spatial and Temporal variations in the population ecology of few intertidal mollusca of a rocky shore of South Saurashtra coastline, Arabian Sea." Presented in International Symposium on Environmental Pollution Ecology and Human Health, Department of Zoology, S. V. University, Tirupati on 25 – 27th July 2009.

- "Spatial and Temporal variations in the population dynamics of few intertidal macrofauna of a rocky shore of South Saurashtra coastline." Presented in XXII Gujarat Science Congress 2008, Bhavnagar University, Bhavnagar, Gujarat on 9th March 2008.

- "Structure of Intertidal assemblage and Population ecology of two constituent molluscan species at an anthropogenically influenced rocky coast." Presented in Symposium on Trends in Biological Sciences, Department of Biosciences, Saurashtra University, Rajkot on 16-17th September 2010.

PUBLICATIONS

- **Vaghela A.**, Bhadja P., Ramoliya J., Patel N., and Kundu R. (2010). Seasonal variations in the water quality, diversity and population ecology of intertidal macrofauna at an industrially influenced coast. Journal of Water Science and Technology, 61(6): 1505-1514. (IWA Publishing, US/UK). *IF-2009: 1.24*.

- **Vaghela A.** and Kundu R., Spatial and temporal variations in the population ecology of two hermit crab species on the South Saurashtra coastline off Arabian Sea. Indian Journal of Marine Sciences. *Communicated*

- Other three Papers are in different stages of communication.

Plate : 1. Map showing the Study Locations at the Saurashra Coastline.

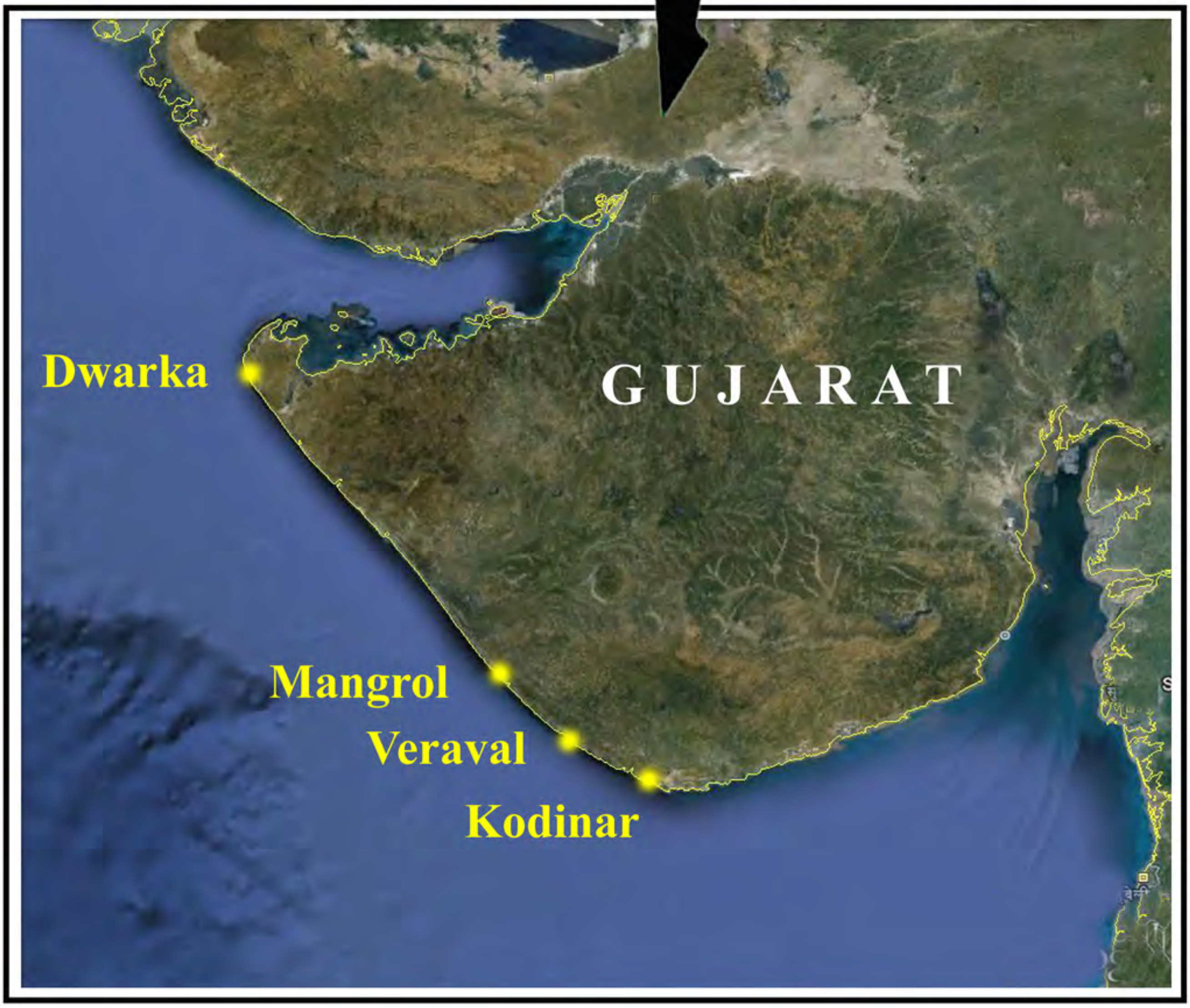


Plate 2: Sampling site Dwarka

Plate 3: Sampling site Mangrol

Plate 4: Sampling site Veraval

Plate 5: Sampling site Kodinar

Plate : 6

Halichondria panicea

Microciona sp.

Tethya sp.

Plate : 7

Anthopleura sp.

Auralia aurita

Isaurus tuberculata

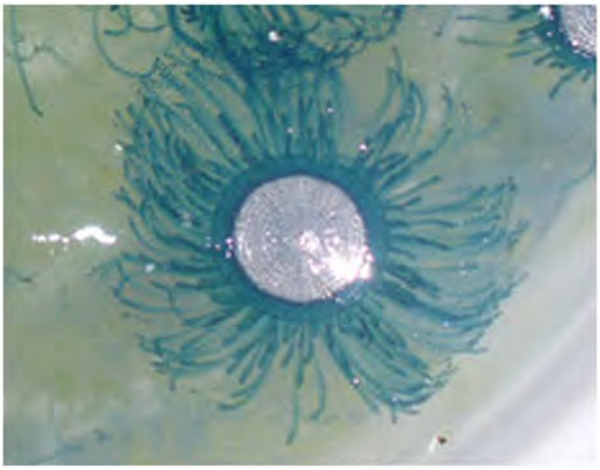
Metridium sp.

Zoanthus sociatus

Utricina sp.

Plate : 8

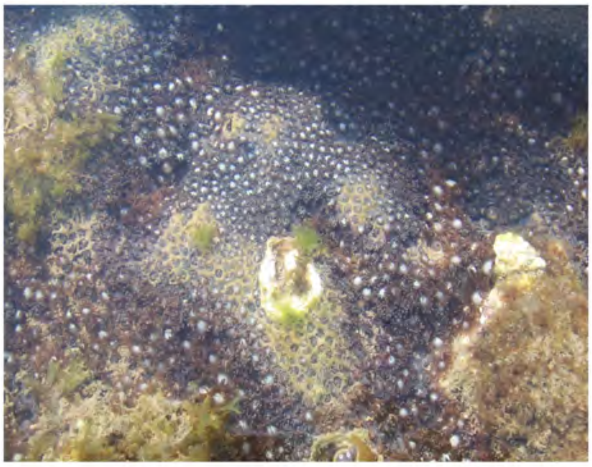
Porpita porpita



Vellella vellella

Goniastraea pectinata

Goniopora sp.



Hydnophora exesa

Montipora folisa

Plate : 9

Portis lutea

Pseudoceros indicus

Pseudoceros susanae

Pseudobiceros stellae

Baseodicus hemprichii

Eurythoa complanata

Plate : 10

Chetopterus chetopterus

Eulalia viridis

Nereis pelagica

Serpula vermicularis

Sabella pavonica

Balanus amphitrite

Plate : 11

Clibanarius nathi

Clibanarius zebra

Cancer pagurus

Pachygrapsus crassipes

portunus pelagicius

Pilumnus hirtellus

Plate : 12

Palaemon serratus

Aplysia oculifera

Brusa granularis

Cantharus undosus

Cantharus spirallis

Berthellina citrina

Austrea stellata

Conus figulinus

Chiton peregrinus

Cerithium scabridum

Cerithium columna

Cellana radiata

Plate : 14

Cerethium morus

Nassarius olivacea

Engina zea

Murex bruneus

Mitra scutulata

Cyprea ocellata

Plate : 15

Venus reticulate

Trochus radiatus

Turbo cornetus

Tibia insuladchorab

Sunetta donacia

Pyrene flava

Plate : 16

Perpura panama

Octopus vulgaris

Onchidium verruculatum

Nerita chamaeleon

Nassarius canaliculata

Murex ternispina

Plate : 17

Antedon sp.

Asterina gibbosa

Ophioderma brevispinum

Echinus sp.

Plate : 18

Boergesenia forbesii

Ulva lactuca

Udotea patiolata

Bryopsis plumose

Cladophora glomerata

Caulerpa racemosa

Plate : 19

Padina gymnospora

Stoechospermum sp.

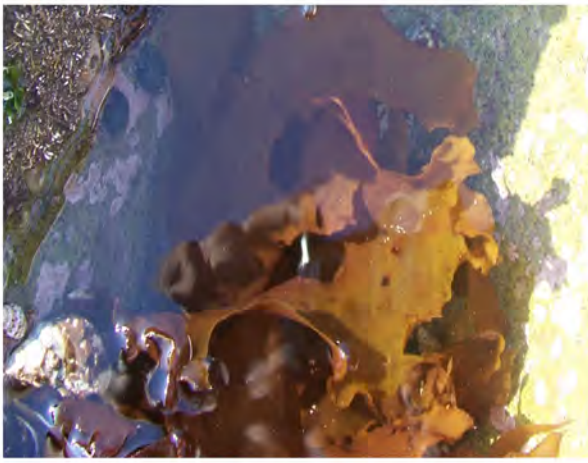
Hydroclathrus clathratus

Sargassum swartzii

Colpomenia tuberculata

Cystoseria indica

Grateloupia indica



Laurencia papillosa

Halymenia venusta

Gracilaria corticata

Galaxaura oblongata

Champia indica

Plate 21. Dwarka

Plate 22. Mangrol

Plate 23. Veraval

Plate 24. Kodinar